Recommendations for an Inland Bays Watershed Water Quality Buffer System

by Christopher Bason
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The Delaware Center for the Inland Bays

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by Christopher Bason, Science & Technical Coordinator, the Delaware Center for the Inland Bays

on behalf of the Scientific and Technical Advisory Committee of the Delaware Center for the Inland Bays,

Dr. Sergio Huerta, Chair

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Cover: Aerial photography of Dirickson Creek, Inland Bays Watershed, Sussex County, Delaware.

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This document provides science-based recommendations for a water quality buffer system designed to protect and restore the quality of wetlands and waterbodies of the Inland Bays watershed located in coastal Sussex County, Delaware. The document focuses on the long-term nutrient removal and retention function of buffers with respect to the total maximum daily load (TMDL) reductions of nitrogen and phosphorus needed for the Inland Bays and their tributaries. A Pollution Control Strategy (PCS) is being developed to meet these reductions in a timely fashion. The PCS is also a major tactic of the Inland Bays Comprehensive Conservation and Management Plan (CCMP) which has among its major goals 1) requiring the maximization of open space in developments, 2) establishing shoreline setbacks regulations that maintain tidal marshes, and 3) securing maximum protection for wetlands and waterways. Literature focused on Atlantic Coastal Plain buffers was reviewed to recommend buffer alternatives by waterbody type and by buffer system characteristics. The alternatives were then applied to eleven randomly selected developments to determine acreage of buffer zones in buildable areas. Further recommendations based on these results are then provided.

Executive Summary

1. Water quality buffers are natural areas between waterbodies and active landuses that are managed for the primary purposes of 1) sustainable removal and retention of excess nutrients entering waterbodies, 2) protecting waterbodies against encroachment and physical alterations and 3) allowing waterbodies themselves to maximize their own capacity to ameliorate pollution.
2. Buffers in small watersheds of the coastal plain have been shown to remove 23 to 65 lbs. of nitrogen and 1.1 to 2.6 lbs of phosphorus per acre of buffer per year. Buffers can remove pollutants from groundwater, surface water runoff, and from in-stream flow while improving the condition of the waterbody they buffer.
3. The 40 to 85% reductions of nitrogen and phosphorus loads needed to restore the water quality and habitats of the Inland Bays, combined with uncertainty in their achievement due to changes in landuse and climate suggests that an extensive and effective riparian buffer system should be included in the PCS.
4. Forested buffers are on average 36% more effective at nitrogen removal than grassed buffers and can improve instream processing of nutrients.
5. Wider buffers remove higher levels of nutrients, and buffers over 150 feet are more likely to meet their maximum potential for nitrogen removal. Variable width buffers remove lower levels of pollutants than fixed width buffers of the same average width.
6. To maximize the efficiency and sustainability of a buffer system, buffers should a) be required on all new subdivisions and redevelopments, b) be forested, c) begin from the wetland-upland boundary of a riparian area, d) and be of sufficient width to allow tidal wetlands to migrate inland with sea level rise.
7. Two buffer system alternatives with different pollution removal performances based on differences in buffer width are provided. The adequate protection alternative provides buffers of 80’ on non-tidal waterways, 80’ on riparian wetlands, 80’ on tidal areas by steep uplands, 300’ on tidal areas by gradual uplands, and 50’ on freshwater flats and depressional wetlands. The optimum protection alternative provides buffers of 150’ on non-tidal waterways, 150’ on riparian wetlands, 150’ on tidal areas by steep uplands, 500’ on tidal areas by gradual uplands, and 100’ on freshwater flats and depressional wetlands.
8. An analysis of the buffer systems applied to developments in the watershed revealed that buffer acreage was highly variable and controlled by the type, amount, and distribution of waterbodies within a development. On average, buffer area fell within the range of Sussex County open space requirements (adequate protection = 13.8% and optimum protection = 33.2% of buildable area). Those developments with tidal areas by gradual uplands, those in the southern region of the watershed, and those that are smaller, will often have to modify site design to accommodate buffer acreage. Governments should cooperate to refine their codes to enable and encourage site design that accommodates buffers.
9. To better accommodate buffers of more functionally important wetlands and waterways, shallow ditches should be disconnected from the drainage network where feasible, or alternatively afforded narrower buffers. Narrow buffers on shallow ditches substantially reduced total buffer area while likely retaining much functionality. Governments should encourage cooperation within and among developments to reduce ditch networks and further improve nutrient reduction in remaining ditches.

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Abbreviations: CCMP, Comprehensive Conservation and Management Plan; CIB, Center for the Inland Bays; DNREC, Department of Natural Resources and Environmental Control; ERES Exceptional Recreational and Ecological Significance; PCS, Pollution Control Strategy; PLUS, Preliminary Land Use Service

Introduction

The Inland Bays are degraded Waters of Exceptional Recreational and Ecological Significance (ERES) that are committed to being restored, by both government and stakeholder groups, to a healthy condition. The ERES designation affords the Bays a level of protection that goes beyond most other waters of the State. Commitments to the protection and restoration of the Bays are detailed in the Comprehensive Conservation and Management Plan (CCMP) for these estuaries of national significance. In this guiding document, buffers for waterways and wetlands are essential to CCMP tactics including implementing the Pollution Control Strategy (PCS), maximizing open space for environmentally sensitive development, and establishing shoreline setbacks to protect tidal ecosystems. Specifically, the CCMP has as one of its most important goals requiring maximum protection of waterways, groundwater, natural areas, open space, and tidal and non-tidal wetlands. Buffers are a necessary component of protecting the Inland Bays because they maintain critical habitat and are highly effective at removing and retaining pollutants for the long-term, with little maintenance costs or risk of failure.

Water quality buffers are natural areas between active landuses and wetlands or waterways that are managed for the primary purposes of 1) sustainable removal and retention of excess nutrients entering waterbodies, 2) protecting wetlands or waterways against encroachment and physical alterations and 3) allowing wetlands or waterways to maximize their own natural capacities to ameliorate pollution. Buffers vary in their capacity to improve and protect water quality based on a number of different factors including buffer vegetation type, buffer width, and physiographic region of the country or world.

Despite the large number of studies on the water quality functions of buffers [3], regulations requiring buffers have been developed using little scientific input or using studies from regions with different physical and ecological characteristics. This report develops science based alternatives for a water quality buffer system in the Inland Bays watershed by reviewing studies conducted in the Atlantic Coastal Plain,[1] and complemented, where needed, by wider reviews of buffer effectiveness. While buffers are best managed to maximize the host of ecological services that they provide, the recommendations here were developed to maximize the efficiency of pollution reduction from buffers implemented at the development of land, per the regulatory intent of the Inland Bays PCS. The alternatives are intended to provide options for implementing the recommendations. This report recognizes that all environmental regulations are developed within the framework of past and present legal, social, and economic conditions, and it at times refers to these factors specific to the Inland Bays watershed. It is hoped that this approach proves educational for others developing recommendations under other such conditions, and should not limit the use of the report as a reference for other watersheds of the Atlantic Coastal Plain.

The Condition of the Inland Bays and the Strategy to Restore Them

"The ecology of the Bays has changed… from a clear water system that supported bay grasses, bay scallops and a variety of shellfish, finfish, and waterfowl to a murky water system that no longer supports a healthy ecology but one that engenders toxic algal blooms, nuisance seaweed blooms, low oxygen episodes, and one that suppresses bay grasses, bay scallops, and the variety and abundance of shellfish, finfish and waterfowl seen earlier [4]." This eutrophic system now contains very high levels of nitrogen and phosphorus which promotes excessive algal blooms including harmful red tides, brown tides, nuisance seaweeds, and dangerous and sometimes fatal levels of oxygen for fish and shellfish. Reductions of nitrogen and phosphorus loads of 40 – 85% are needed to meet the standards selected for the restoration of bay water quality. The reductions were modeled through a Total Maximum Daily Load (TMDL) analysis using baseline data from 1988 to 1990 and they include a margin of safety to account for uncertainty [5, 6].

To meet the reductions in a timely manner, a PCS has been drafted by DNREC based on input by the CIB, DNREC, and the public. The draft PCS includes sections addressing water quality buffers, the reduction of agricultural and urban sources, onsite wastewater systems, stormwater management, government accountability, and the elimination of point sources [7].

Factors Affecting TMDL Achievement

To put the development of a buffer system as a part of the PCS into context, a number of influential factors affecting TMDL achievement are considered. First, an implicit margin of safety to account for uncertainty related to field data interpretation and modeling was included within TMDL development [5, 6]. This supports the likelihood of a timely achievement of the TMDL. In contrast, a number of factors add uncertainty to the timely achievement of the TMDL under the current PCS. Of primary consideration is the level of development that has been permitted without PCS protections in critical areas of the watershed. At the time of this report, over 60,000

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[1] The Atlantic Coastal Plain is a physical region of the United States where similar geology, hydrology, and resulting patterns of landuse makes ecological comparisons more relevant.

housing units were under construction, had been permitted, or were under review for permit in Sussex County [8]. Much of this growth is concentrated in the Environmentally Sensitive Area of the Inland Bays watershed. A draft analysis by DNREC determined that new construction raises pre-construction phosphorus loads by 30% [9]. Nitrogen loads are estimated to decrease by 15%, but this is far from the lowest reduction target of 40%. This suggests that additional amounts of nutrients will need to be reduced watershed-wide to meet TMDLs. It also increases the difficulty of meeting reduction goals for both phosphorus and nitrogen from this new development, because pollution control opportunities and cost efficiencies decrease post construction. Additionally, as permitted development occurs, it is expected that the nutrient processing capacity of the streams that drain these areas will decline [see 10, 11].

Other factors that add uncertainty to meeting the TMDL are the predictions of increased runoff, nitrogen loading[2], and saltmarsh loss (and associated nutrient assimilation capacity) resulting from climate change (see [12, 13]); all of which were not considered during TMDL or PCS development. Finally, the primarily voluntary actions of the PCS combined with past difficulties in obtaining compliance with water quality regulations in the watershed, [14, 15] do not add confidence to the achievement of nutrient reductions. These factors suggest that a buffer system with the maximum efficiency to reduce pollutant loads be required as a part of the PCS.

Condition of the Watershed Stream Network

Streams function as the arteries and wetlands the kidneys of the watershed; together they supply and filter water moving towards estuaries. Thus the acreage and health of these systems affects estuarine water quality. Buffers are implemented to not only reduce and remove nitrogen and phosphorus travelling towards water bodies, but also to protect and improve the capacity of wetlands and waterways to themselves filter pollutants. In the Inland Bays watershed, wetlands and waterways have been severely altered and are limited in their capacity to reduce pollution. Sixty percent of the watershed's freshwater wetlands were eliminated since European settlement [16]. Further, a quarter of the watershed's tidal wetlands were eliminated between 1938 and 1980 [17]. The condition of the remaining Inland Bays wetlands was being assessed at the time of this report. Preliminary information shows that over 75% of riverine (streamside) wetlands have highly degraded hydrologic and water quality functions [16]. These wetlands are impacted by inadequate buffers and pervasive hydrologic modifications. In particular, stream channelization (channel excavation) has increased the delivery of nutrients to streams and disconnected streams from their adjacent wetland filters. The condition of the watershed's streams themselves is also poor with 29% supporting their designated societal uses [7]. Nutrient and bacteria pollution, lax enforcement of existing regulations, ditching and stream channelization practices, and the lack of buffers has contributed to this condition. DNREC describes 78% of rivers, streams, and ditches in the watershed as inadequately buffered [18]. Buffer implementation should begin to restore the capacity of waterbodies to treat pollution and protect them from the effects of development.

Effects of Development on Waterways

Wetlands and waterways face increased stress as the watershed develops. The watershed is the fastest growing region of the State with developed lands increasing by 35% from 1992 to 2002 [7]. In the mid-Atlantic, the more development that occurs and the closer it is to a waterbody, the greater chance those aquatic resources will be degraded [19]. Elsewhere, permanent degradation of rivers and streams has been shown to occur as a watershed's impervious cover exceeds 25-60% (see Miltner et al. 2004 and references therein) [20]. Increases in impervious surfaces generally increases stream channel erosion and the speed at which pollutants are delivered downstream. This results in streams downcutting their channels and losing connection with their streamside wetland filters. It also reduces the capacity for riparian areas to filter nutrients from groundwater and the capacity for in-stream processing of nutrients [10, 21]. Research suggests that the nutrient processing capacity of waterways will likely decline as the permitted development in our watershed occurs [10, 11].

To date, development without the required buffers and adequate sediment and stormwater controls have stressed waterways (Figure 1). Buffers of tidal wetlands and waters have particularly been affected by lax enforcement of existing County regulations. Buffers maintained or installed prior to development can help to control runoff from an active construction site, and filter delayed discharges of high nitrogen groundwater from previously existing agricultural operations and more distant, ongoing farms [22].

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[2] Climate change during this century is likely to have a profound effect on nutrient loading to estuaries. Predictions for increased precipitation in the mid-Atlantic suggest that both river flows and the fraction of land-applied nitrogen entering estuaries will increase. This could increase the number of "wet years" our estuary experiences when nutrient pollution and its affects are more severe (see citations in text above).

Figure 1. Typical examples of inadequate water quality buffers and sediment and erosion control from the Inland Bays watershed, 2006/2007. A. Chronically silted ditch on construction site with fertilized turf grass buffer. B. Sediment control failure and lack of buffer near White's Creek. C. Excessive turbidity from runoff in White's Creek and construction site with minimal buffer. Parts of the buffer here leaves little if any room for wetland migration with rising sea levels. D. Fertilized turfgrass buffer and exposed sediment near freshwater wetland. E. Lack of buffer on new development on Dirickson's Creek. F. Seamless transition from saltmarsh to golfcourse.

The Case for Riparian Buffers

Mass balance studies that measure all watershed inputs and outputs provide the most accurate estimates of buffer effectiveness to reduce pollution. The Atlantic Coastal Plain is fortunate to have multiple nutrient mass balance studies of buffers. In small coastal plain watersheds with well-buffered waterways, riparian zones retained from 23 to 65 pounds of nitrogen per acre of buffer per year (67 – 89% of inputs) and 1.1 to 2.6 pounds of phosphorus per acre of buffer per year (24 – 81% of inputs) [23, 24]. Difference in effectiveness of individual buffers results from the great amount of natural variability among riparian areas [25]. On the whole, compelling evidence exists for the use of buffers to restore water quality, and the characteristics of buffers that best accomplish this are reviewed below.

Planning Buffers for the Whole Watershed: Why Different Waterbody Types Require Different Buffers

Watersheds have different types of waterbodies, all with their own unique set of characteristics. Figure 2 illustrates these waterbodies and describes some of their water quality functions. There are the Bays themselves, their tidal tributaries, the freshwater streams of varying sizes, and the network of ditches that extends the natural drainage system. There are also wetlands of various types including tidal marshes, riparian (streamside) wetlands, flats wetlands such as the Great Cypress Swamp, and depressional wetlands such as Delmarva bays (Figure 3). Because these wetland and waterway types occur at different positions on the landscape, they receive water from different sources and thus function somewhat differently [26, 27]. For example, tidal wetlands move inland with rising sea levels while nontidal wetlands generally do not. People also interact with each waterbody type in different ways, and thus tend to appreciate their various functions more or less based on these interactions. For example, most homeowners seem to prefer a view across the waters of a tidal marsh, but usually do not manage their properties for a view across a drainage ditch. Waterway and wetland types are given individual consideration to design the most efficient buffer system.

Table 1. Wetland and waterway classification for a watershed buffer system.

Tidal Wetlands and Waters
Gradual Upland/Wetland Boundary
Steep Upland/Wetland Boundary
Nontidal Wetlands and Waterways
Wetlands
Flats and Depressional Wetlands
Riparian Wetlands
Headwaters
Larger Streams
Constructed Ditches

The wetland and waterway classification developed for this report is presented as Table 1. It is one of many potential classification schemes. Tidal wetlands and waterways are separated from nontidal wetlands and waterways because tidal systems move with rising sea levels. Headwaters are separated from larger streams because they are the most important for water quality protection and can be so numerous that their buffers can have a relatively greater impact on how a parcel is developed. Ditches are separated from natural streams because filling or integrating ditches into a stormwater management system during development can result in more spatially efficient nutrient reductions relative to buffering ditches as they are. Riparian wetlands are separated from flats and depressional wetlands because they are more directly connected to flowing waterways.

This literature review focuses on buffers of waterways and their associated wetlands, generally called riparian areas. Less study has been given to water quality buffers of flats and depressional wetlands, and thus less review is presented. However, flats and depressions remain important to water quality protection, because they make up about three quarters of all freshwater wetland acreage [28]

~ In small coastal plain watersheds with well-buffered waterways, riparian zones retained from 23 to 65 pounds of nitrogen per acre of buffer per year (67 – 89% of inputs) and 1.1 to 2.6 pounds of phosphorus per acre of buffer per year (24 – 81% of inputs) ~

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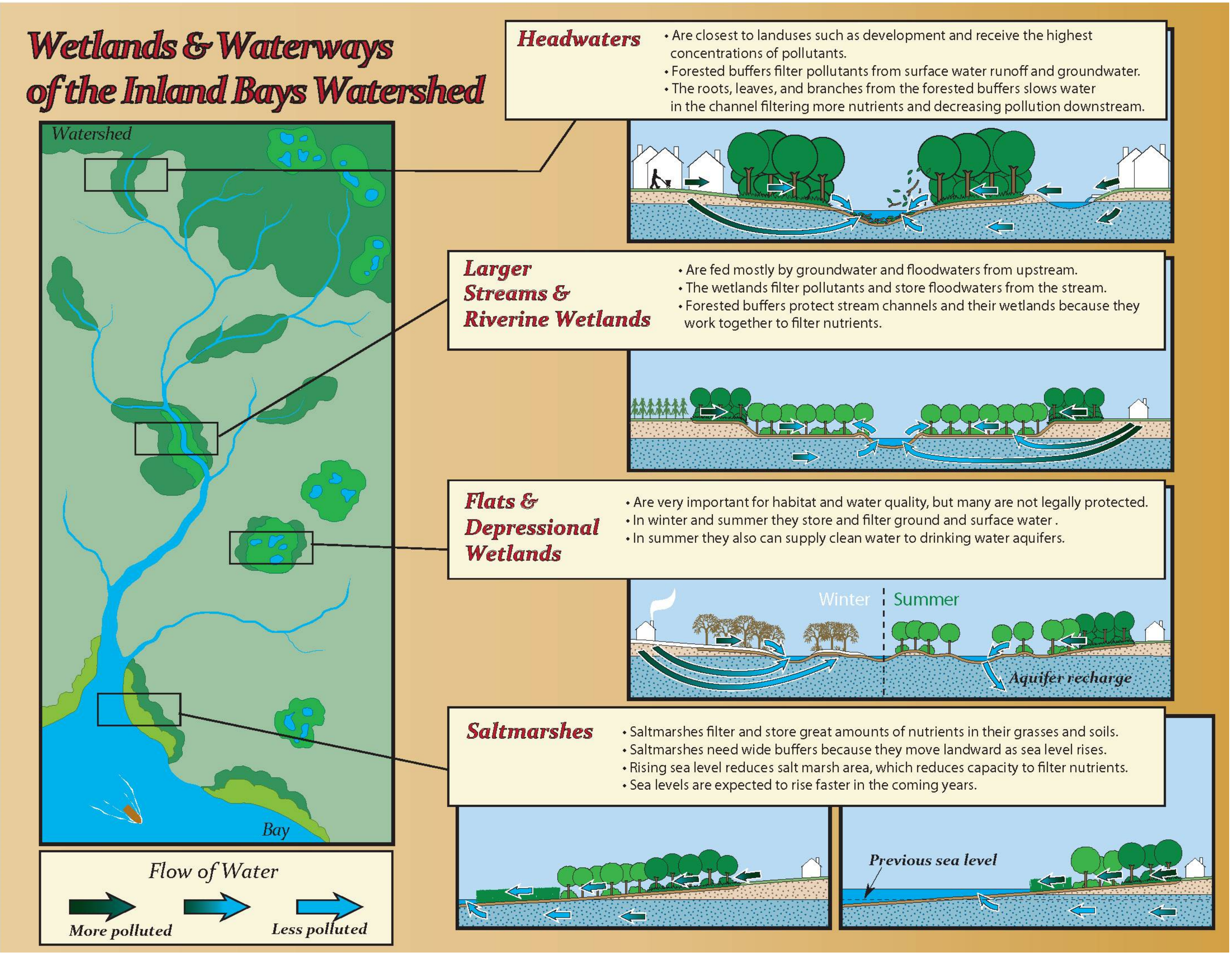

Headwaters

- Are closest to landuses such as development and receive the highest concentrations of pollutants.
- Forested buffers filter pollutants from surface water runoff and groundwater.
- The roots, leaves, and branches from the forested buffers slows water in the channel filtering more nutrients and decreasing pollution downstream.

Larger Streams & Riverine Wetlands

- Are fed mostly by groundwater and floodwaters from upstream.
- The wetlands filter pollutants and store floodwaters from the stream.
- Forested buffers protect stream channels and their wetlands because they work together to filter nutrients.

Flats & Depressional Wetlands

- Are very important for habitat and water quality, but many are not legally protected.
- In winter and summer they store and filter ground and surface water .
- In summer they also can supply clean water to drinking water aquifers.

Saltmarshes

- Saltmarshes filter and store great amounts of nutrients in their grasses and soils.
- Saltmarshes need wide buffers because they move landward as sea level rises.
- Rising sea level reduces salt marsh area, which reduces capacity to filter nutrients.
- Sea levels are expected to rise faster in the coming years.

Figure 2. Wetland and waterway types of the Inland Bays watershed.

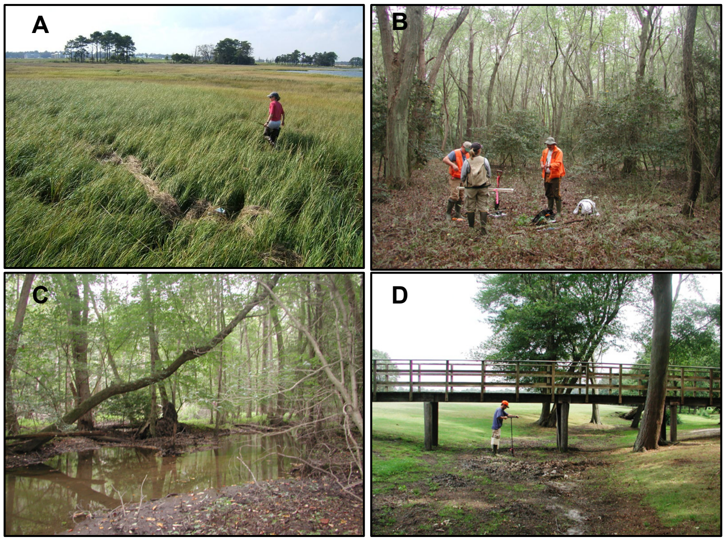

Fig. 3. Examples of wetland and waterway types in the Inland Bays watershed. A. Tidal marsh with gradual upland-wetland boundary in background. B. Freshwater flats wetland. C. Larger natural stream with extensive riparian wetlands. D. Headwaters without adjacent wetlands.

Sources of Water and Pollution to Riparian Ecosystems

Riparian areas receive water primarily from groundwater, runoff, and upstream flow [26] (Figure 4). Tidal areas also receive water from the Bays, and direct precipitation supplies water to all wetlands. While buffers act to remove pollution from all sources of water to varying degrees, nitrogen primarily enters and is removed from groundwater flow [29] and phosphorus primarily from surface runoff [30] (*but see Box 1*). Once through a riparian buffer, much of the remaining nitrogen and phosphorus enters ditch or stream channels that flow toward the Bays. Thus a comprehensive buffer system should be developed to control pollution from upstream flows, adjacent surface water runoff, and groundwater; not just runoff as is sometimes focused on. In fact, runoff comprises a small portion of hydrologic inputs to waterbodies of the watershed. As much as 80% of precipitation not evapotranspired, infiltrates into the earth to become groundwater on its way to the Bays [31]. Similarly, nearly three quarters of all nitrogen is delivered to Rehoboth Bay through groundwater [32], placing emphasis on the capacity of buffers to treat this source of water and associated pollution.

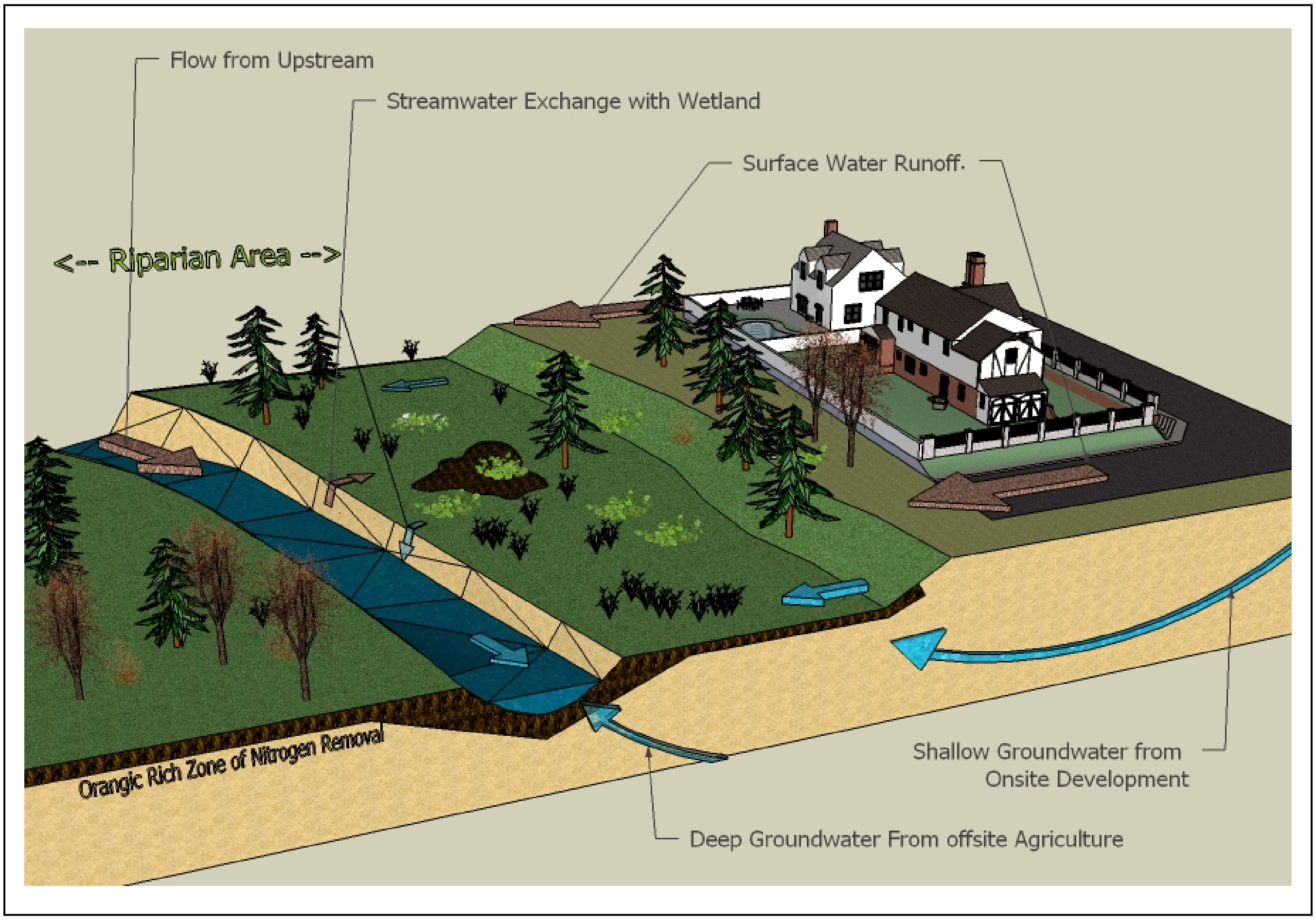

Fig 4. Conceptual model of the primary sources of water and pollution to riparian areas. Arrows indicate flows.

BOX 1. Phosphorus In Groundwater.

Phosphorus in groundwater is a particular concern for the Inland Bays watershed. Phosphorus can leach into groundwater to be later absorbed by riparian buffers [1]. But this function of buffers has been overwhelmed in some areas by over-application of phosphorus rich poultry manure on agricultural fields. Certain soils in our watershed are naturally susceptible to phosphorus leaching and because they are phosphorus-saturated, will do less to control this pollutant even after converted to development [2]. Identification of these areas by soil type and phosphorus status could be used to prioritize areas of wider buffers or soil amendments that might make up for this deficiency. The laboratory of Tom Sims at the University of Delaware has been working to identify these soils and developing methods to better bind excess phosphorus to soils.

Groundwater

Groundwater flows are often classified as shallow and deep groundwater. Shallow groundwater comes from lands close to a waterbody, including designated buffers, and discharges within a few months to a few years. Shallow groundwater is the most plentiful for most of our waterways, and it tends to pass through zones of nitrogen removal in healthy riparian areas. Deep groundwater takes longer flow paths from lands more distant from waterbodies, and may take 20 to 50 years to discharge. Deep groundwater may discharge directly to the bottom of a waterbody, bypassing important areas of nutrient removal in certain riparian zones of well drained landscapes [33, 34]. Deep groundwater means that decades may pass before reduction in some pollutant loads finally begin to improve surface water quality. But it also means that buffers installed now can treat pollution from years when there was little nutrient management.

There is variation in how waterways receive groundwater and associated pollutants. Waterways can receive disproportionately more or less groundwater because of their orientation relative to the direction of groundwater flow [35]. Also, not all groundwater discharges evenly along riparian zones. Some groundwater follows preferential flow paths, where discharge concentrates into a riparian area. Preferential flow paths may form due to small differences in soil texture along a riparian zone or they may form due to larger features such as lateral ditches [36-39]. These relatively small areas of the total riparian zone can be responsible for disproportionate amounts of nitrogen discharge to a waterway (40% of nitrogen discharge in one study) [38]. Buffer systems should avoid gaps and maintain a consistent minimum effective width for maximum water quality protection [40], partly to ensure areas of preferential flow paths are fully addressed.

In-stream Processing of Nutrients

The power of stream channels to treat pollutants is often overlooked. Waterways are not just drains but complex ecosystems with the capacity to retain pollution from waters flowing downstream [41-43]. Their capacity to do so varies with their condition [10, 44-46], with healthier streams retaining more pollutants. For example, channelized streams (or those that have had their channels excavated to increase drainage) have higher nitrogen and phosphorus concentrations [46], and much of the sediment loads to downstream waters originate from within the channels of such eroding waterways [47, 48]. This may be especially so in watersheds where development and stream channelization has increased the hydrologic energy of waterways. Streams with fewer hydrologic alterations provide more tortuous flowpaths and a greater hydrologic exchange with any adjacent wetlands which results in more opportunities for pollutant trapping and removal.

Direct Precipitation

All wetlands receive part of their water from precipitation that falls directly onto their surfaces. In the Inland Bays watershed, wet and dry atmospheric deposition of nitrogen and phosphorus make up a significant portion of nutrient inputs, especially during the summer months [49, 50]. Because flats and depressional wetlands tend to receive the greatest portion of their water from precipitation [26], they are particularly important for their role as interceptors and filters of this nutrient source. Furthermore, the fact that these types comprise the great majority of freshwater wetlands in the watershed (~75%) increases their importance in reducing pollution from direct precipitation. It is also notable that these wetland types are most likely to be considered non-jurisdictional under the federal Clean Water Act [51] and thereby legally unprotected in the State of Delaware at the writing of this report.

Developing A Buffer System One Characteristic at a Time

This section uses the available literature to develop recommendations for a buffer system with maximum efficiency to reduce pollutants. Each identified characteristic of a buffer system including extent, vegetation, width, waterbody type, and buffer restoration is treated by asking and answering questions.

Buffer Extent

What Waterways are the Most Important to Buffer?

To maximize the effectiveness of a watershed buffer system, all waterways that are to remain after development should be buffered. However, headwater streams are particularly recognized for their importance in reducing nitrogen loads downstream. Rates of nitrogen removal are higher in headwaters relative to larger waterways [42, 43, 52, 53]. Headwaters make up approximately 75% of total waterway length in watersheds [27, 54]. They tend to have the highest nitrate concentrations [55] because they are in the closest connection with the sources of pollution from the surrounding landuse [27]. And their small and shallow geometry allow water the greatest opportunity to interact with areas of the highest nutrient removal on the bottom and sides of the channel (Figure 6). Among waterways, the headwaters should be afforded the most protective buffers.

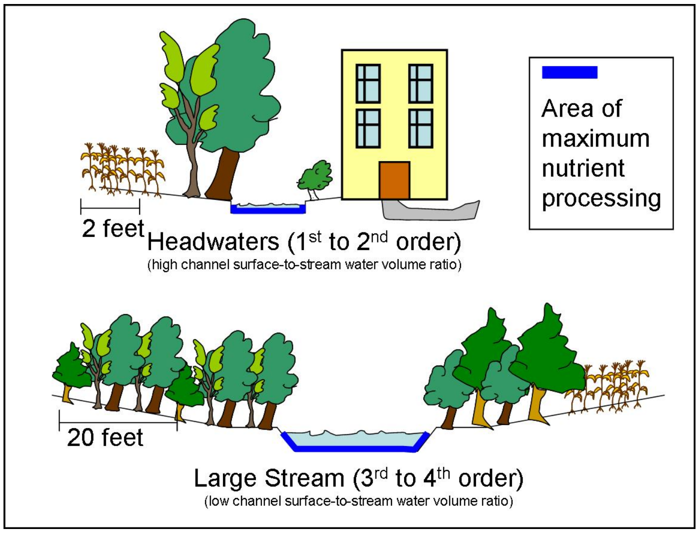

Fig. 6. Headwaters are smaller, more numerous, more closely connected to the surrounding landuse, and provide proportionately greater areas of nutrient processing than larger streams. For stream order explanation see section directly below.

How Can Headwaters be differentiated from Larger Streams?

Because headwaters are the most important for water quality protection, they will need to be differentiated from larger streams in order to be assigned the most protective buffers. Conversely, the great numbers of headwater ditches in the southern portion of the watershed (see below), may here require narrower buffers to accommodate development. A consistent method of differentiating headwaters from other waterways can facilitate requiring buffers with different characteristics including width.

One common method of differentiating waterways is to split them between those that normally flow perennially, and those that normally flow intermittently throughout the year. However, rapid determination of a waterways' flow regime as intermittent or perennial is difficult due to great variation in the flow patterns of the upstream drainage network and due to short and long-term changes in weather. Further, topographic maps indicate waterways categorized as perennial or intermittent based on observations that did not correspond well with the category definitions; and this can be a source of confusion. A more consistent and simple approach is to map the drainage network and assign waterways as either headwaters or larger streams based on their position in the drainage network. Unfortunately, many headwaters do not appear on coastal plain topographic maps and soil surveys that are commonly used for resource planning, and thus their protection cannot be ensured from plan review. Accurate, detailed and standardized maps of headwaters should be developed prior to regulation (see Baker et al. 2007) [56]. North Carolina is an example of a state that has undertaken this work, and one such tested method from their coastal plain is included as Appendix 1.

During the mapping process, natural streams should be differentiated from ditches. This can facilitate flexibility for land planners to fill those ditches that will not significantly impact on or off site drainage. Filling of unnecessary ditches will also help to restore stream network hydrology, reduce pollutant transport, and minimize buffer areas.

The Strahler stream order method [57] is suggested for designating headwaters. Using this approach, first order streams have no tributaries. Second order streams start at the confluence of two first order streams. The confluence of two second order streams is a third order stream, and so on. Often, first and second order streams are together designated as headwaters [58, 59].

In a Riparian Ecosystem, Where Should the Buffer Begin: From the Edge of the Wetland or the Edge of the Channel?

Stream channels and their adjacent wetlands are inextricably linked in their natural capacity to filter pollution [60]. Even small streams in the watershed support wetlands. Because coastal plain stream slopes are gradual, channels regularly flood their banks after rains allowing the wetlands to slow and store water and to filter pollutants. Groundwater also discharges laterally into streamside wetlands where it is filtered and this can occur preferentially at the landward edge of the wetland [37]. To fully protect stream channels and their wetlands buffers should begin from the upland/wetland boundary and not from the channel. Figure 7 illustrates this concept. Buffering from the upland/wetland boundary 1) eliminates a potential source area of excess nutrients that is closest to surface waters, 2) retains any existing forest buffering the wetland 3) provides full protection to wetlands themselves from common residential impacts such as filling, grading, and sediment runoff. Buffering from the channel may not even include the existing streamside wetlands in the buffer area. Former floodplains that have drained and are no longer wetlands but are within stream valleys should also be protected. Providing a buffer around these areas offers the opportunity for future restoration of the water quality functions of the former floodplain [61].

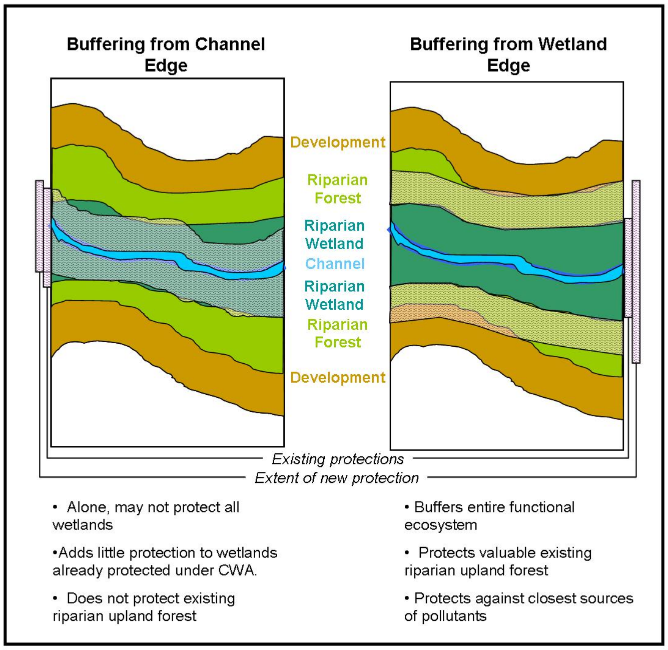

Fig 7. The effect of buffering from channel or wetland edge in riparian areas. CWA = federal Clean Water Act.

Buffer Vegetation Type

The type of vegetation in a buffer influences the hydrology and nutrient processing capacity of riparian areas. Since most coastal plain streams have no rocks, the roots, logs, and branches of a forest provide the structure that influences how streams flow. Forests hold the sediments of streams in place and provide the coarse and dissolved organic material that helps remove nitrogen.

What Type of Vegetation Reduces the Most Nutrients?

Studies of this question have focused on the efficiency of native grass versus forested buffers (Figure 8). In general, forests reduce more nitrogen than other buffers [62, 63], but little coastal plain specific information is available. Data from a wide ranging review indicated that, on average, forested buffers reduced 36% more nitrogen than grassed buffers[3][29]. This difference may be smaller when corrected for differences in width. Another comprehensive study in the Piedmont found that headwaters with forested buffers had dramatically higher rates of in-stream nitrogen uptake than those without forests in their buffers[64].

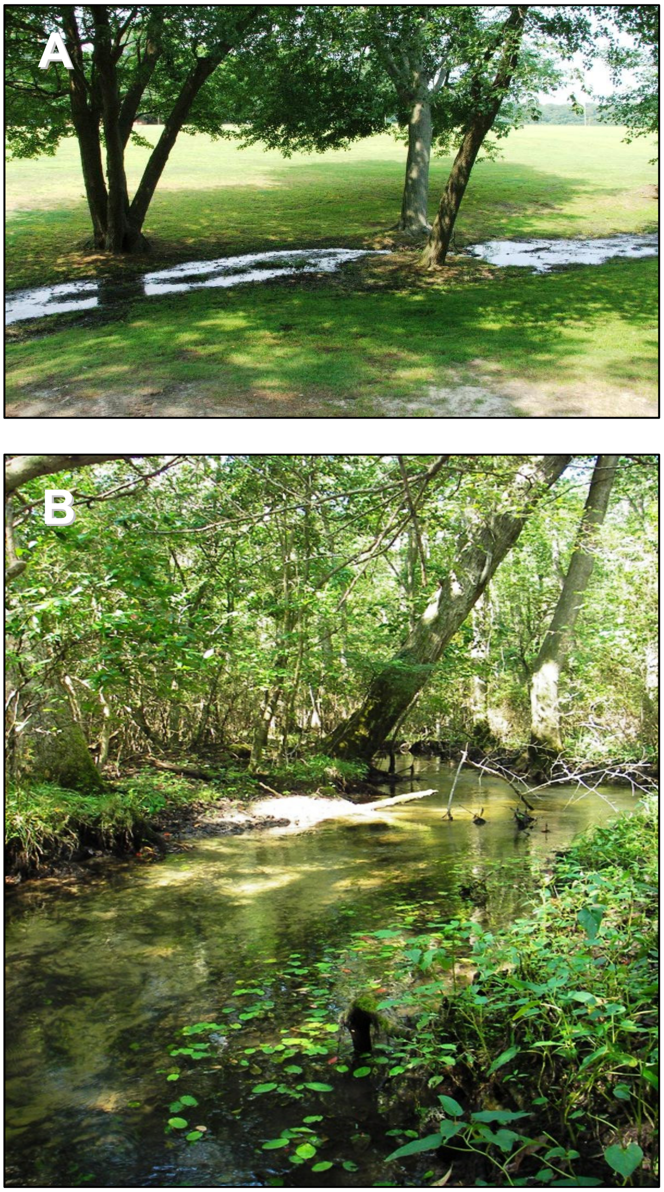

Fig 8. Turfgrass (A) versus forested (B) buffers. Note the differences in complexity, aboveground nutrient storage, and habitat quality.

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[3] Forested buffers are the weighted average of forested and forested wetland buffers for 29 studies (mean reduction = 88.8%); grassed buffers were from 22 studies (mean reduction 53.3%).

Why Do Forested Buffers Reduce more Nutrients than Turf or Grass Buffers?

1. Forests have greater long-term nutrient storage than grass buffers because they have more biomass. Coastal plain riparian forests uptake 11 to 37 pounds of nitrogen and 1.5 to 4.5 pounds of phosphorus per acre each year into their woody biomass [23, 65-67]. This form of nutrient removal and storage capacity is not present in turf or grass buffers.
2. Forests continue increasing their aboveground biomass until about 90 years of age [44] (Figure 9) Root and soil biomass likely continues to increase beyond 90 years.
3. Soil organic matter is over twice as high in forested buffers than grassed buffers, providing more potential for nitrogen removal [44].
4. The presence of an adequate carbon supply [(organic matter)] is the most commonly identified critical factor for nitrogen removal in a riparian area[68].
5. Forested buffers provide well developed zones of organic rich material directly below and adjacent to streams that remove nitrogen in groundwater [63]. These zones can be smaller and sparse in non-forested buffers (Figure 10).
6. The large roots of forest trees provide solid physical structure to stream channels, preventing erosion, slowing water, and increasing water flowpaths (e.g. [69]) which increases nitrogen removal.

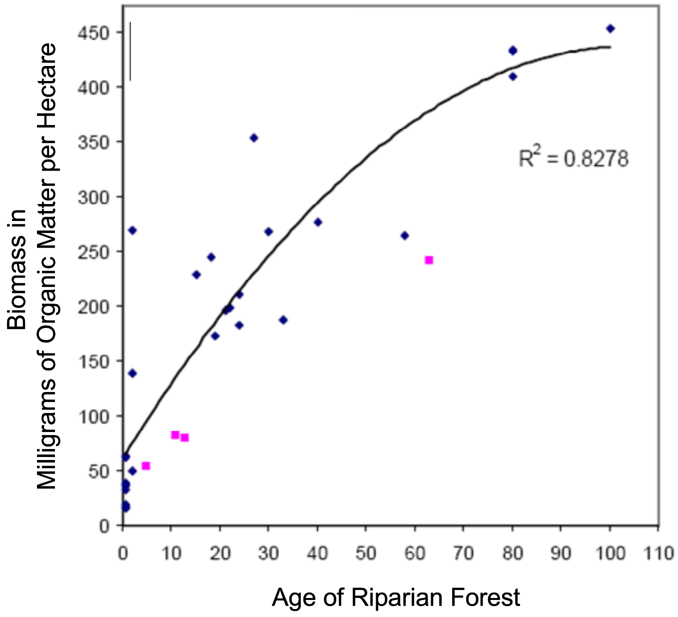

Fig. 9. Increase of headwaters riparian forest biomass with age in the North Carolina Coastal Plain. Blue diamonds are from Brinson et al. 2006 [44] and pink squares are from Giese et al. 2003 [70]. Adapted from Brinson et al. 2006.

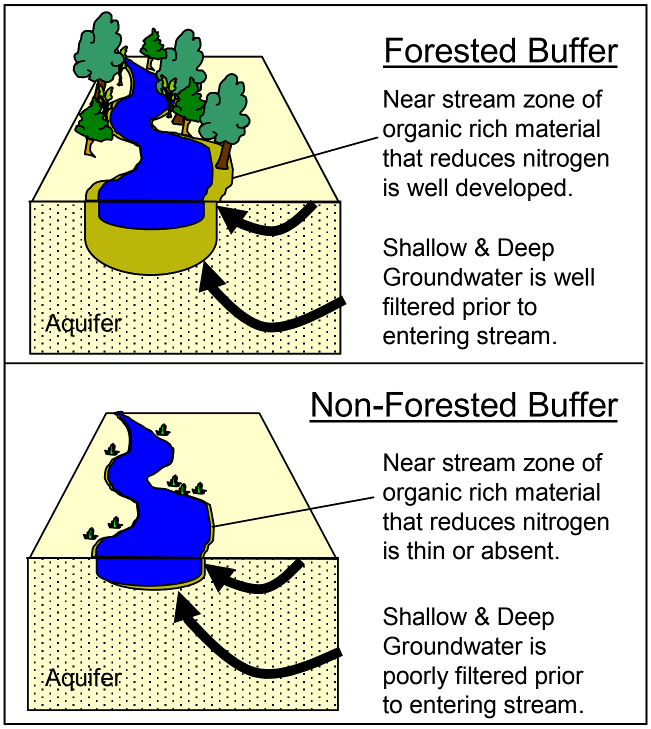

Fig. 10. Differences in the near stream zones nitrogen removal between forested and non-forested riparian buffers. Adapted from Spruill 2000 [63].

Buffer Width

Next to extent, width is perhaps the most important ecologic and economic characteristic of a buffer system, because it affects both pollutant removal efficiency and where development can or cannot occur. Independent scientific reviews have recommended widths whereby buffers generally meet their potential for removing nitrogen and phosphorus. The recommended widths are consistently around 100 feet (Table 2). However, it is important to note that these and other reviews include studies from around the globe. To reduce the variation resulting from such different areas of the nation and world, studies from the Atlantic Coastal Plain were analyzed separately below.

Table 2. Recommended buffer width for water quality protection from scientific reviews.

Study	Width (ft)	Comments
Environmental Law Institute 2003 [71]	82	Recommended minimum width
Schueler & Holland 2000 [72]	100	Typical mean width recommended
Christensen 2000 [73]	100	
Wenger & Fowler 2000 [74, 75]	100	Recommended minimum

Nitrogen

Seventeen coastal plain buffer studies were analyzed for the effect of width on nitrogen removal[4]. Most data points were taken from a wider analysis conducted by Mayer et al. 2007[29]. It could not be determined if wetlands were present adjacent to the waterways buffered for many of the studies. It is assumed that some buffers included streamside wetlands while some did not. A single rectangular hyperbola curve demonstrated the best fit to the plotted data. A strong relationship between buffer width and efficiency was found in this analysis that was not observed for Mayer et al.'s wider study (R^2 = 0.67 and 0.09 respectively)(Figure 11). The data indicates a point between 80 and 90 feet, where only about a 2% increase in removal efficiency is gained with each additional foot of width. At 80 feet wide, buffers averaged nearly 80% nitrogen removal, with at least 67% removal occurring for most buffers (95% confidence interval lower bound). The data also suggests a threshold of 150 feet and above where buffers more consistently reach their maximum potential for nitrogen removal. Figure 12 shows the significantly greater and less variable nitrogen removal for buffers over 150 feet, here repeating Mayer et al's. results.

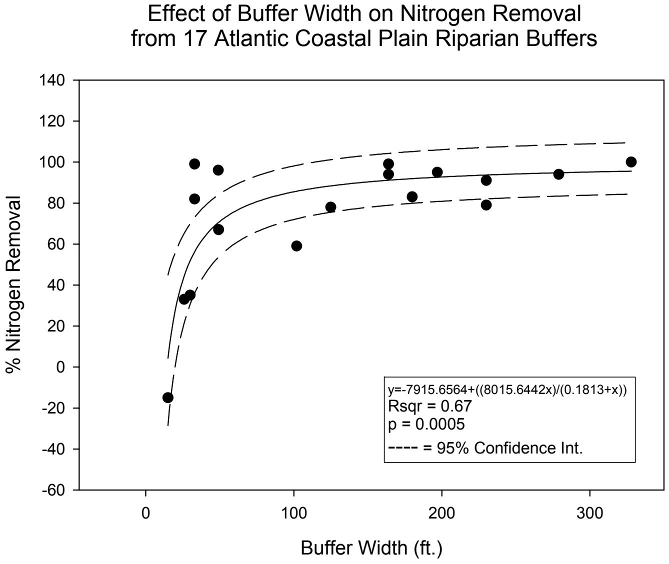

Fig. 11. Effect of buffer width on nitrogen removal from 17 Atlantic Coastal Plain riparian buffers. Appendix 2 includes a table of study references.

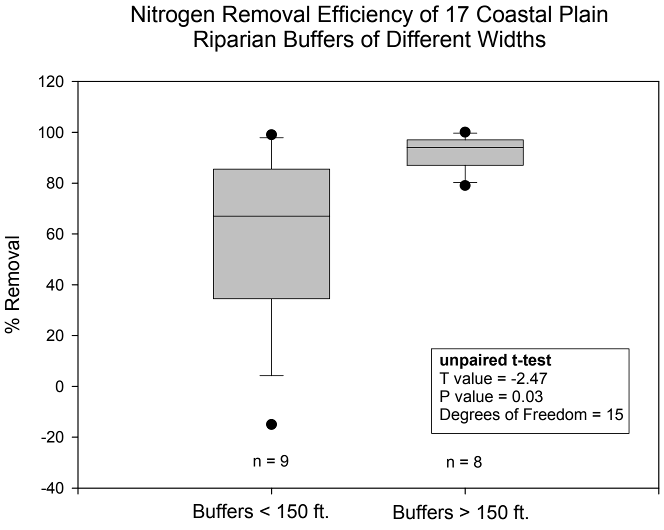

Figure 12. Nitrogen removal efficiency of 17 coastal plain riparian buffers of different widths. Boxplots lines are the median, 25th percentile, 75th percentile, whiskers are the 10 and 90th percentiles, and dots are the outliers of the distributions for buffers less than and greater than 150 feet.

Phosphorus

Only six studies comparing buffer width to phosphorus removal were found for the coastal plain. It could not be determined if wetlands were present adjacent to the waterways buffered for many of the studies. It is assumed that some buffers included streamside wetlands while some did not. The few studies precluded determining a relationship (Figure 13). Data from Desbonnet et al.'s [76] review of buffers from multiple regions plus data from two additional studies suggested that phosphorus removal increased with width in a similar but more variable fashion than nitrogen removal. However, this relationship was not found to be statistically significant, and the data are here presented without a trendline ($y=10.2*\ln(\text{buffer width})+21.4$, $R^2 = 0.13$, $p = 0.25$) (Figure 14).

The data does suggest a threshold where variation in phosphorus removal decreases near 80 feet and buffers more consistently remove high levels of phosphorus. At around 80 feet, removal averaged 66% with around 50% removal occurring for most buffers (lower 95% confidence interval of the above regression). It is likely that for this wide array of studies, width has a small effect on phosphorus retention relative to other factors.

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[4] Buffers adjacent to manure or treatment effluent application were not included in this analysis and one 656 foot wide buffer was not included as its width was an outlier, over twice as the width of the next widest buffer.

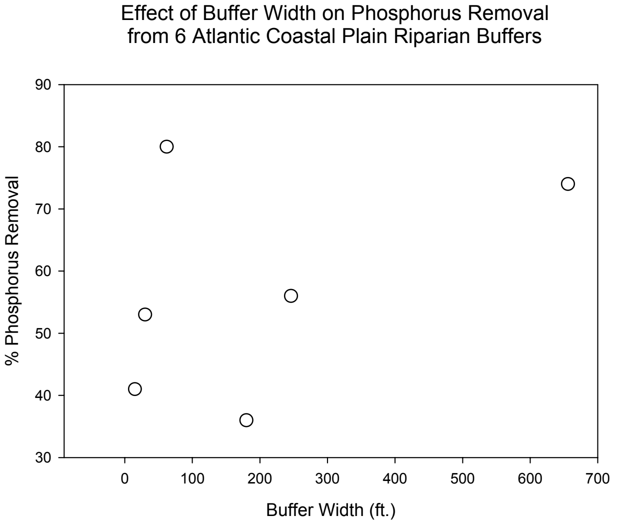

Figure 13. Effect of buffer width on phosphorus removal from 6 Atlantic Coastal Plain riparian buffers. Appendix 2 includes a table of study references.

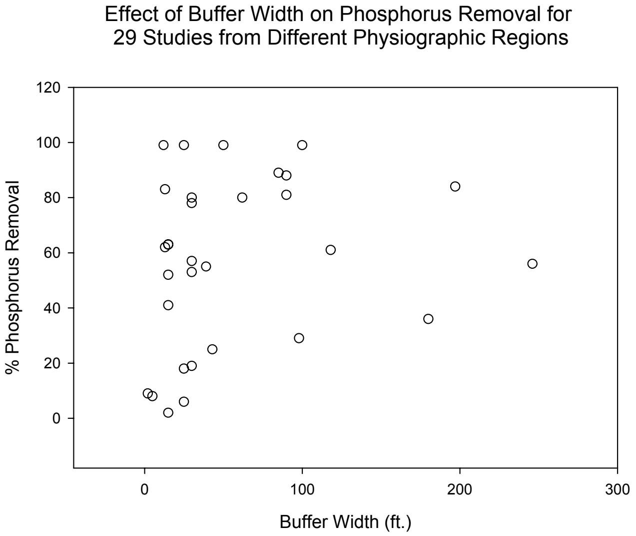

Figure 14. The relationship between riparian buffer width and phosphorus removal for many study regions. Data from Desbonnet et al. 1994 [76] and two additional studies cited in Appendix 2.

What is the absolute minimum recommended width for a buffer allowed to vary in thickness along the length of a single waterway?

A variable width buffer of a specified average width that is along a single water feature should be assigned an absolute minimum width at any one point that is able to maintain pollution removal. Below this minimum width, it is assumed that buffer function may become significantly reduced or overwhelmed by sediment inputs or invasive species. However, no known empirical studies exist on minimum sustainable widths. One recent review commented that little experimental evidence is available for the efficiency of narrow buffers [77]. The Chesapeake Bay Program cited an absolute minimum buffer width of 35 feet to provide sustainable protection of aquatic resources [78]. Wenger recommended an absolute minimum width of 30 feet for trapping sediment [74].

Variable versus Fixed Width Buffers

Variable and fixed width buffer systems each have their own environmental and regulatory pros and cons. Buffers of a sufficient fixed width provide simplicity and consistency for regulatory purposes and have been shown to be more efficient at controlling pollution, but provide less flexibility for siting homes in a development. On the other hand, variable width buffers are likely to require more effort for accurate regulatory review, inspection and enforcement; and should do less to control pollution, but can provide more flexibility for home siting. However, variable width buffers, if implemented with regards to watershed and site-level differences in hydrogeology, can attempt to maximize pollution removal efficiency and maintain flexibility for development.

Why are Variable Width Buffers Less Effective?

Weller et al. modelled how the efficiency of buffers changed between variable and fixed width systems [40]. Variable width buffers remove lower levels of pollutants than fixed width buffers of equivalent average width. This is so because areas of narrow or absent buffers contribute relatively high levels of pollution. The extra pollutant discharge from below average width buffers is more than the extra pollutant retention from above average width buffers. So to reduce the same amount of pollutants a variable width buffer must be wider on average than a fixed width buffer. The difference in removal between fixed width and variable width buffers was greatest for narrow buffers. The amount by which variable width buffers contribute more pollution changed with the quality of the buffer, based on a factor such as vegetation type. Work in Wisconsin also suggested that uniform buffers are more important for phosphorus removal [79].

The importance of minimizing gaps in buffers and inefficient buffer widths has been repeated elsewhere. To the extent that the minimum effective buffer width is maintained, it is more effective to have continuous but narrow riparian buffers, than wider but discontinuous buffers [40, 61]. David Correll, also of the Smithsonian Environmental Research Center, remarked after a career studying riparian zones that, “Perhaps the most important guiding principles to emerge from the current scientific literature that should be considered when implementing riparian setback regulations are: (1) The importance of contiguity in riparian protection and (2) The great value and importance of protecting the least disturbed riparian corridors in communities[80].”

What can be done to Maximize the Effectiveness of Variable Width Buffers?
At the watershed level, minimum buffer widths can be assigned based on the characteristics of different parts of the watershed (see The Two Regions of the Watershed and What they Mean for Riparian Buffer Width). At the site level, buffers can be planned using precision information [81]. This approach uses topographic, hydrologic, soils, and landuse information to maximize the effectiveness and efficiency of buffers on a site. Pollutants may enter waterways through compromised buffers or preferential flow paths. The precision approach can enhance buffers on a site by placing more buffer in these areas. In a simple example, buffers are widest along waterways where surface and subsurface drainage patterns route a large fraction of pollutants. Figure 15 compares the fixed width buffer approach with the variable width precision approach. Soils information, specific pollutant source location, and on site groundwater flow studies can be applied to increase the precision of buffer placement. In concert with an overall minimum buffer width and a policy of eliminating gaps this is an effective and flexible approach, but one that requires detailed study of certain site characteristics.

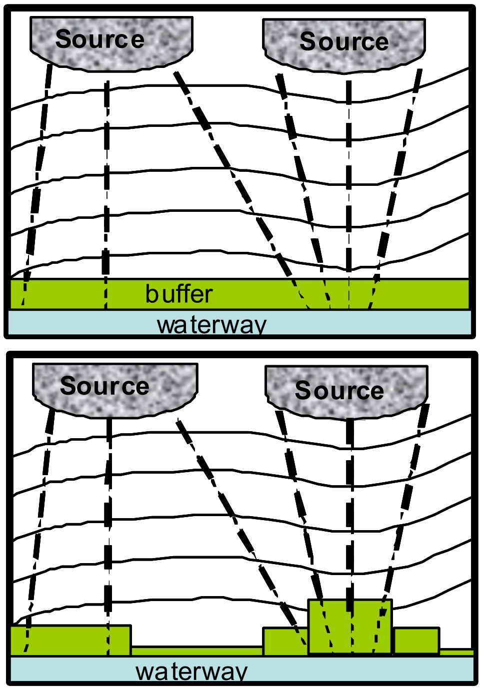

Figure 15. A comparison of two approaches to buffer width: fixed at top and precision variable width at bottom. Relatively large sources of pollutants concentrate their discharge to waterways across topographic contours. Adapted from Dossekey et al. 2005[81].

The Two Regions of the Watershed and What they Mean for Riparian Buffer Width

The geology, hydrology and resulting patterns of landuse differ between the northern and southern areas of the watershed. These areas have been previously defined as hydrogeomorphic regions by the USGS [33], and their regions are simplified and presented here for the purposes of a buffer strategy [33][5] (Figure 16). The differences between these regions are summarized in Table 3. The northern region or the Well Drained Region has a gently rolling topography, soils that are well drained and low in organic matter, and few ditches. The southern region or the, Poorly Drained Region, is relatively flat, has higher water tables, less permeable soils with high organic matter content, and many ditches. From a buffering perspective, this would suggest that the capacity of buffers to treat groundwater would be higher in the Poorly Drained Region and perhaps could justify a smaller minimum buffer width. This is so because the low-permeability, highly organic soils provide longer residence times in the near surface area of buffers where nitrogen removal is high [82].

Table 3. Relative characteristics of two simplified hydrogeomorphic regions of the Inland Bays Watershed.

Characteristic	Well Drained Region	Poorly Drained Region
Topography	Very gently rolling	Flat
Riparian Slope	Steeper	More gradual
Water table	Lower	High
Groundwater flow	Rapid	Slower
Soil Permeability	High	Low
Soil Organic Matter	Low	High
Drainage Ditch Density	Low	Very High
Wetlands Area	Low	High
Subsurface Confining Areas	Few	More
Potential for Groundwater Nitrogen Removal by Buffers[33, 82]	Medium	High

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[5] Well Drained Uplands is mostly well-drained upland with some poorly drained upland and coastal wetland and beach region from the USGS categorization. Poorly Drained Lowlands is mostly surficial confined with some poorly drained lowland and coastal wetland and beach regions from the USGS.

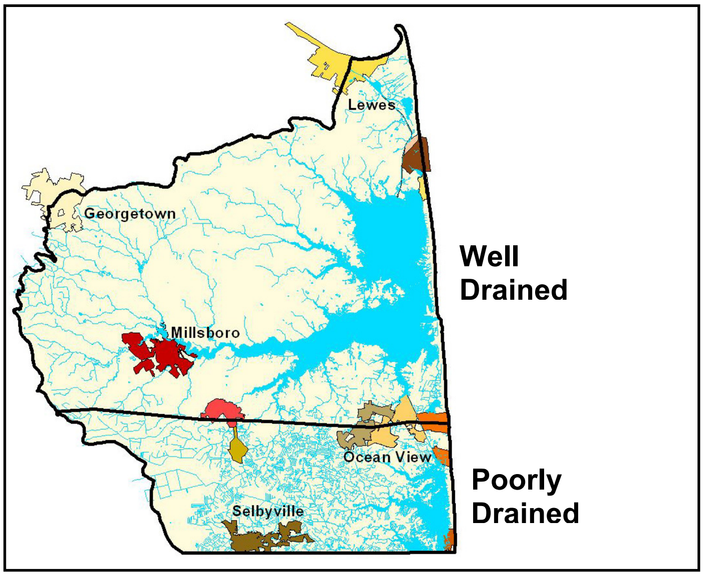

Figure 16. The two simplified hydrogeomorphic regions of the Inland Bays watershed. Water features are in blue. Note the differences in drainage density between the two regions.

Tidal Wetlands & Waters

Tidal wetlands have a great capacity to remove nitrogen inputs [83] and can do so even when their width is narrow. As much as 75% of the nitrogen from the Rehoboth Bay watershed moves as groundwater that regularly discharges near and within tidal wetlands [32, 84]. This supports the buffering of all tidal wetlands. Tidal wetlands and waters require special concern for buffering because they migrate inland with sea level rise, reducing the width of their buffers over time. Once migrating marshes meet development, homeowners will protect their property by raising or armoring the upland-wetland interface, if this was not already done during site preparation. At this point, inland migration slows or generally stops but moderate to rapid erosion [85 and references therein] of the bayward edge continues, resulting in the wetlands eventually being "pinched out" of existence. This places the maintenance of tidal wetlands under extraordinary pressure from development because their existence in the absence of continual restorative efforts depends upon inland migration. Development already permitted around the Bays with absent or narrow buffers will contribute to an eventual large scale loss of wetland resources. Requiring buffers of widths that accommodate long-term wetland migration will protect remaining areas of these existing biofilters for the long-term. Buffers of tidal wetlands are also essential to protecting critical fish and bird nursery habitat, carbon storage and sequestration capacity, and other functions that support the health of the Inland Bays.

How Wide Should Buffers of Tidal Areas Be?

Buffers of tidal areas should maximize nutrient removal and allow their inland migration. Given typical resource management planning horizons of 50 to 100 years, wetland migration rates will primarily determine the width of buffers on tidal areas. Rates of migration are primarily controlled by the slope of the upland-wetland interface, with more gradual slopes resulting in greater rates. Inland Bays specific rates of migration are presented as Table 4 [85].

Table 4. Average landward migration rates of tidal wetlands in feet per year by adjacent upland slope from 1944-1989. Gradual Slope = <0.08 rise/run, Steep Slope = >0.09 rise/run. Valley Axis refers to tidal creeks. [85 page 131].

Slope of Wetland-Upland Interface	Indian River Bay	Rehoboth Bay
Gradual	5.25	6.07
Steep	1.44	0.82
Valley Axis	16.40	4.56

The rates were used to calculate upland buffer widths that can be reasonably assumed to protect wetlands for different planning horizons (Table 5). After the number of years indicated, the average wetland is assumed to have fully migrated over the buffer. Over the time horizons, upland buffers are assumed to lose some effectiveness as their width decreases. No empirical data could be found to quantify these decreases in effectiveness. The data used to develop the presented widths are likely conservative, such that the increase in tidal amplitudes of the Bays since the period of analysis and predicted increases in rates sea level rise were not accounted for. These factors suggest that actual rates of migration may now be greater and could continue to increase, and thus selection of wider buffer widths relative to planning horizon goals should be considered.

Table 5. Average number of years upland buffers of different widths and slopes will provide protection to tidal wetlands or waters. Gradual Slope = <0.08 rise/run, Steep Slope = >0.09 rise/run.

Upland Buffer Width	Indian River Bay Gradual Slope	Indian River Bay Steep Slope	Rehoboth Bay Gradual Slope	Rehoboth Bay Steep Slope
50'	10	35	8	61
75'	14	52	12	91
100'	19	69	17	122
200'	38	139	33	244
300'	57	208	49	366
400'	76	278	66	488
500'	95	347	82	610

It is recommended that buffers of freshwater flats wetlands adjacent to tidal wetlands should be assigned buffer widths based on the estimated rate of migration of the tidal wetlands. Additionally, because the influence of tides rapidly moves upstream as sea level rises, a length of freshwater stream that is adjacently upstream to a tidal stream should be afforded buffer widths equal to those of buffers of tidal waters. This should apply to a length of these freshwater streams that is equal to the length that tidal influence will encroach over a determined planning horizon. Appendix 3 explains the methodology used to develop tidal buffer width recommendations in more detail.

How Can Viewscapes Across Tidal Areas be Provided in Buffers?

The demand for residential viewscapes across tidal areas suggests that the recommended requirement of forested buffers be refined. Views would likely not be possible across the wide forested buffers recommended above. Only requiring forested vegetation nearest to the upland wetland/waterway boundary would allow for viewscapes. To maximize the efficiency of the buffer, the forested zone should be as wide as possible while still allowing acceptable views. The 80 foot buffer width for nontidal waterways and riparian wetlands is recommended as minimum forested width for wide buffers of tidal areas. Management could enhance selected view corridors while allowing denser forest in other sections. Evidence suggests that such management would have little effect on at least subsurface nitrate processing [86]. In wide buffers, non-permanent landuse and structures could be located further landward from the buffered feature. A management plan could require tree planting in the non-forested part of the buffer relative to the rate of estimated landward migration of the wetland.

Figure 17. Example of maintained forested buffer that provides a viewscape onto White's Creek and its marshes (photo taken in early spring).

Freshwater Flats and Depressional Wetlands

No research could be found that specifically recommended a minimum buffer width to protect the water quality functions of freshwater flats and depressional wetlands. However, it has been documented that the direct and indirect impacts of development and deforestation near a wetland can cause irreversible changes to its hydrology and species composition [87, 88]. Development also leads to increased nutrient loading of wetlands [89]. Together these impacts may result in changes to the nutrient processing capacity of wetlands. Wetlands can "dry out" and their capacity for nitrogen removal can decrease, or they can become wetter, reducing their capacity to store hydrologic inputs [87, 90]. Requiring forested buffers will likely provide greater protection from these impacts than non-forested buffers and remains consistent with the recommendations for other buffer types. More study is needed to better define effective water quality buffer widths for these wetland types. It is more or less arbitrarily recommended that 50-foot and 100-foot buffers be required for these wetland types.

Restoration and Management

Restoration of riparian networks has become a focus water quality improvement efforts. Passive reforestation of buffers within developments is one form of riparian restoration. Opportunities also exist for the accelerated reforestation of buffers at development. Requirements or incentives could be developed that encourage planting of native forest species especially in areas where a native forest is not adjacent to the buffer. Planting buffers provides opportunities to increase stewardship within these areas and accelerates the restoration of water quality functions. A few coastal plain studies have shown increased pollutant removal by buffers shortly after restoration. One buffer was increased from 30 to 98 feet resulting in nitrate removal efficiencies from shallow groundwater increasing from an average 44% to 94% [91]. A mass balance study of another restored riparian wetland showed that within the first 8 years following restoration the buffer was highly effective at reducing nitrogen and phosphorus loads [36]. On average, restored buffers appear to have a substantial effect on nitrate removal within 5 – 10 years [82].

Requiring buffers at the development poses an temporary opportunity to implement physical restoration activities within degraded waterways. After development, opportunities to access sites with heavy equipment decline. Further incentives and cost-share agreements should be formulated to take advantage of this opportunity by encouraging developers to cooperatively plan and implement restoration with public and private restoration practitioners. Restoration techniques including controlled drainage, check dams, addition of logs, channel reformation, and controlled beaver population introduction can complement the water quality functions of buffers.

Recommendations

The following recommendations for the characteristics of a buffer system are based on the above review of the scientific literature. This first set applies to the entire buffer system and is critical to maximizing the pollution removal potential of buffers and ensuring their implementation.

1. All wetlands and waterways have high potential to filter significant amounts of nutrients and should be buffered, where feasible, for all new subdivisions and redevelopments.
2. Headwaters and those existing natural waterways and wetlands that are in the best ecological condition should receive the most protective buffers.
3. Governments should encourage alternative site designs to ensure implementation of the buffer systems.
4. A variance procedure should be developed to resolve rare instances where buffer requirements may preclude development of a property, especially for small subdivisions.
5. Buffers should begin at the upland edge of streamside wetlands where they are present.
6. Forested riparian buffers provide greater potential for long-term improvement and protection of water quality than non-forested buffers and should be the required vegetation type for all buffers[6].
7. Filling of minor drainage ditches or their incorporation into stormwater management during development should be encouraged where adequate drainage can be maintained especially in the southern portion of the watershed.
8. Where forested buffers are required but do not exist, restoration of native vegetation (typically native hardwood or mixed-pine hardwood forest) should occur.
9. Only water dependent structures and necessary public utilities should be allowed in the buffer zone. Stormwater control features in the buffer should be limited to necessary conveyances and outfalls.
10. New incentives and cost-share agreements should be explored and existing programs promoted to encourage developers to cooperatively plan and implement restoration of degraded wetlands and waterways with restoration practitioners.

The second set of recommendations is for two alternative buffer systems with different levels of protection based on vegetation type and width (Table 6). Alternatives were developed to offer flexibility for developing the Pollution Control Strategy and can be used to incorporate incentives. For example, the first level of protection could be required by regulation, while the higher level of protection could be pursued voluntarily in conjunction with incentives such as faster development permit review. The adequate protection alternative provides around 80% and 66% removal for nitrogen and phosphorus respectively, protects tidal wetlands for approximately 50 – 70 years, and provides 50 foot buffers to flats and depressional wetlands. The optimum protection alternative increases nitrogen and phosphorus removal by about 8%, and provides greater certainty that waterway buffers maximize their pollution removal efficiency. It also protects tidal wetlands for approximately 88 - 132 years, provides 100 foot buffers for flats and depressional wetlands, and provides increased protection of other important wetland and waterway functions. The optimum protection alternative is most consistent with the goals of the Inland Bays CCMP.

Development Analysis

Abstract

A watershed-level GIS analysis explored the dimensions of the recommended buffer systems on 11 randomly selected developments listed by the State of Delaware's Preliminary Landuse Service between February 2004 and January 2007. The percentage of developable acreage as buffer varied widely and averaged 13.8% and 33.2% for the adequate and optimum protection alternatives. Estimates are likely high due to the scale of the analysis. Developments that are small, that are in the Poorly Drained Region, and/or that have tidal wetlands by gradually sloping uplands will have larger buffer areas. The total buffer acreage was evenly distributed between buffers on ditches, freshwater wetlands, and tidal areas. Ditches made up almost all of the freshwater waterway length. Requiring narrower buffers ($\geq$ 35 feet) on shallow ditches (~2 – 3 feet deep) can provide the flexibility needed by developers to site homes and more adequately buffer natural wetlands and waterways. Buffers on most developments can be accommodated within current County open space requirements. Ordinances and incentives that facilitate development site designs to accommodate buffers are likely critical for implementing these recommendations in the Inland Bays watershed.

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[6] Only the areas of buffer within a set distance closest to a tidal feature should be required to be forested (see a).

Table 6. Alternative buffers systems for the Inland Bays watershed with different levels of resource protection. Years next to tidal wetland and waters widths indicate average number of years buffer will provide protection. Notes below indicate estimates of nutrient removal associated with widths.

Buffer System Characteristic	Adequate Protection Alternative	Optimum Protection Alternative
Buffer Width Variation	Variable Width	Fixed Width
Vegetation Type	Dominance of Native Forest†	All Native Forest†
<u>Buffer Width by Type</u>		
Tidal Wetlands & Waters		
Gradual Upland/Wetland Boundary	300 feet (53 yrs)	500 feet (88 yrs)
Steep Upland/Wetland Boundary	80 feet (71 yrs)	150 feet (132 yrs)
Nontidal Wetlands and Waterways		
Flats and Depressional Wetlands	50 feet	100 feet
Riparian Wetlands	80 feet‡‡	150 feet‡‡‡
Headwaters Streams & Ditches	80 feet‡‡	150 feet‡‡‡
Larger Streams & Ditches	80 feet‡‡	150 feet‡‡‡

† See Tidal Wetlands & Waters section for elaboration on a recommended vegetation type for these buffers.

‡‡ Estimated 82% nitrogen removal on average with at least 67% removal for most buffers. 66% phosphorus removal on average with more variability.

‡‡‡Estimated 90% nitrogen removal on average with at least 78% removal for most buffers. 73% phosphorus removal on average with less variability

Methods

A detailed GIS workflow with data sources is attached as Appendix 4 to supplement the general methodology presented here. A shapefile of developments that were submitted to the State's Preliminary Land Use Service (PLUS) from February 2004 to January 2007 were clipped to the Inland Bays Watershed using ArcView 3.2 GIS software. Three or four small developments (under the median acreage of the distribution) and 2 large developments (over the 75th percentile of acreage) were randomly selected from the northern and southern regions of the watershed. For each development, the Delaware State Wetlands Mapping Project layer and a detailed hydrography layer were used to determine the dimensions of wetlands and waterways onsite and offsite whose buffers might intersect the development. Due to the scale of the analysis, the hydrography layer was not updated to include unmapped headwaters and ditches. Ditches were separated from natural waterways. Length of ditches totally within wetlands were not recorded but length of ditches on wetland boundaries were recorded. Ditches were considered to be minor when they had small drainage areas. Minor ditches were evaluated to determine if they were fillable or otherwise able to be disconnected from the drainage network without causing drainage problems upstream. The slope of uplands adjacent to tidal wetlands was estimated as gradual or steep using both hypsography data layers derived from the most recent USGS topographic maps and best professional judgement. LIDAR derived elevation data available for the study area would provide much more accurate estimates but could not be used for this study.

Both protection alternatives were applied to the developments. Areas isolated by buffers such that development was unlikely were recorded. Large isolated areas were assumed buildable with access roads permitted through the buffer. The percent of the developable acreage each buffer alternative would take up was calculated. The contributions to total buffer acreage from buffers of different wetland and waterway types were calculated. The amount of buffer acreage to be restored to forest was determined using the 2002 State landuse data layers. For tidal buffers, only the first 80 or 150 feet from the water or wetland boundary was considered to be required to be restored for the adequate and optimum alternatives respectively. These widths were selected to correspond to efficient widths chosen for non-tidal waterways of the two protection alternatives. Statistics were compiled by development size and hydrogeomorphic region.

Results

GIS Data Layer Accuracy. The hydrography and wetlands data layers demonstrated errors that likely resulted in inflated estimates of buffer acreage on developments. These errors resulted from incorrect mapping of waterways near property boundaries, the over-mapping of freshwater wetlands (inherent to the SWMP data layer), and the assumption that no wetlands would be filled. Furthermore, the extent of tidal wetlands by gradually sloping uplands was likely overestimated.

Development Distribution. One hundred and ten developments in the watershed were recorded by the PLUS for the roughly two years of available data. The distribution of development size is depicted as a histogram in Figure 18. The median development size was 61 acres. The 25th and 75th percentiles were 25 and 106 acres respectively. Nine of the eleven developments (82%) randomly selected for study were located in the Environmentally Sensitive Development Area (Figure 19).

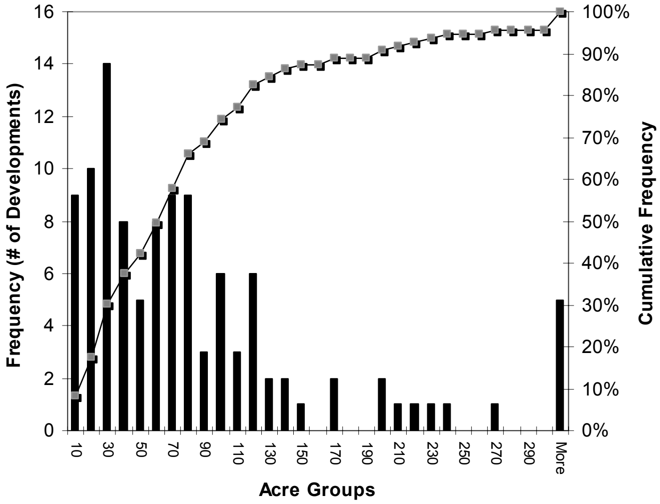

Figure 18. Histogram of development size with cumulative frequency for developments proposed in the Inland Bays watershed from February 2004 to January 2007.

Development Characteristics. Dimensions of the 11 developments, their waterways and wetlands, and their buffers by protection alternative are presented individually as color maps and tables on page 23 to page 33. Appendix 5 contains complete summary tables for the analysis. Site characteristics are summarized in Table 7. The percentage of a site as wetlands had a median value of 12% and ranged from 0% to 67%. Non-tidal wetlands dominated the wetland acreage, and only three sites had tidal wetlands. The percent developable acreage prior to buffering had a median value of 88% and ranged from 33 to 100% of a site. Total waterway length was highly variable and ranged from 0 to 3,362 feet with a mean of 1,615 feet. Only one site had a natural stream so almost all waterway length was of ditches. About half of the ditches (51%) were considered minor ditches. About half of these minor ditches (45%) were considered fillable or otherwise able to be disconnected from the drainage network so that they did not require buffers. A number of developments required buffers of features on adjacent properties.

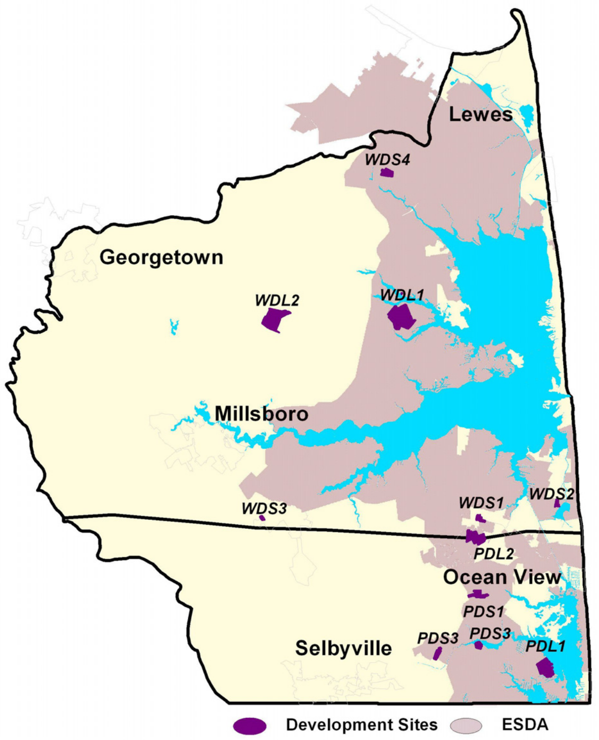

Figure 19. Location of PLUS application development sites analyzed showing the Environmentally Sensitive Development Area (ESDA).

Sites in the Poorly Drained Region had more ditches and more nontidal wetlands than sites in the Well Drained Region (means = 2,220 feet vs. 805 feet and 10.1 acres vs. 3.3 acres, respectively) (Table 8). As a result, the percent developable acreage of sites in the Poorly Drained Region (68%) was less than in the Well Drained Region (89%). Ditch density was surprisingly similar between regions (means = 65.3 and 70.0 respectively)[7], but much higher in smaller (98.3) than larger developments (14.8). (Appendix 5 & Table 9).

Table 7. Site characteristics for eleven study developments.

Site Characteristics	Min	Max	Mean	Median
Site Acreage	8.7	314.0	94.0	50.2
Total Wetland Acreage	0.0	99.7	14.9	4.0
Nontidal Wetlands	0.0	16.4	6.4	3.2
Tidal Wetlands	0.0	88.9	8.5	0.0
Developable Acreage	8.7	308.7	79.0	37.1
Waterway length (ft)	0.0	3362.0	1615.0	1653.0
Stream Length	0.0	150.0	30.0	0.0
Ditch Length	0.0	3362.0	1448.7	1562.0
Minor Ditch Length	0.0	2996.0	979.1	681.0
Fillable Ditch Length	0.0	1993.0	615.8	799.0

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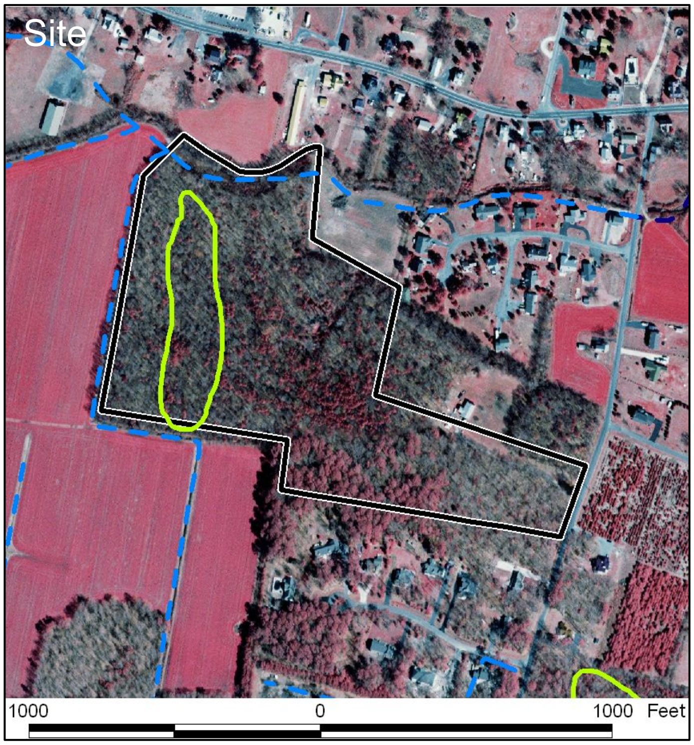
[7] Calculating this including wetlands, where many ditches occur, showed a much greater ditch density in the Poorly Drained Region as expected.

Windhurst Manor

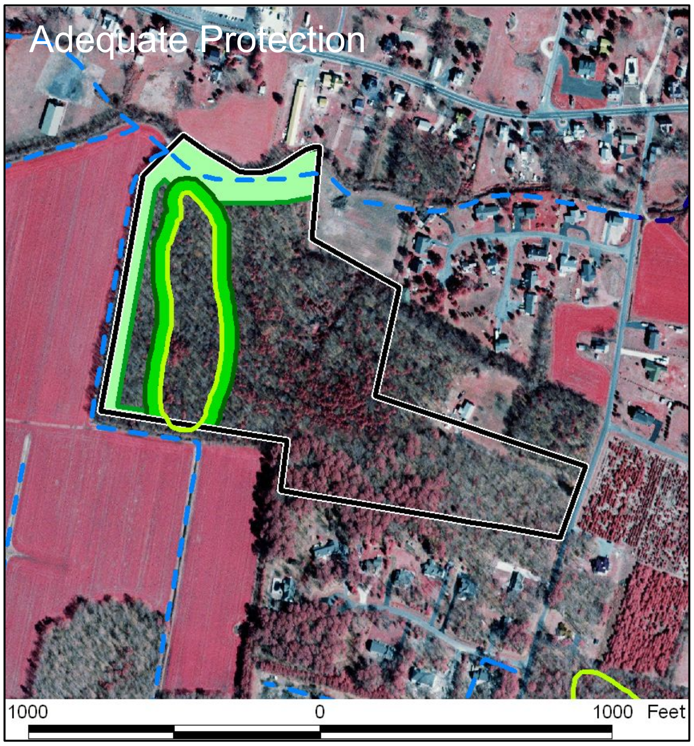
WDS1

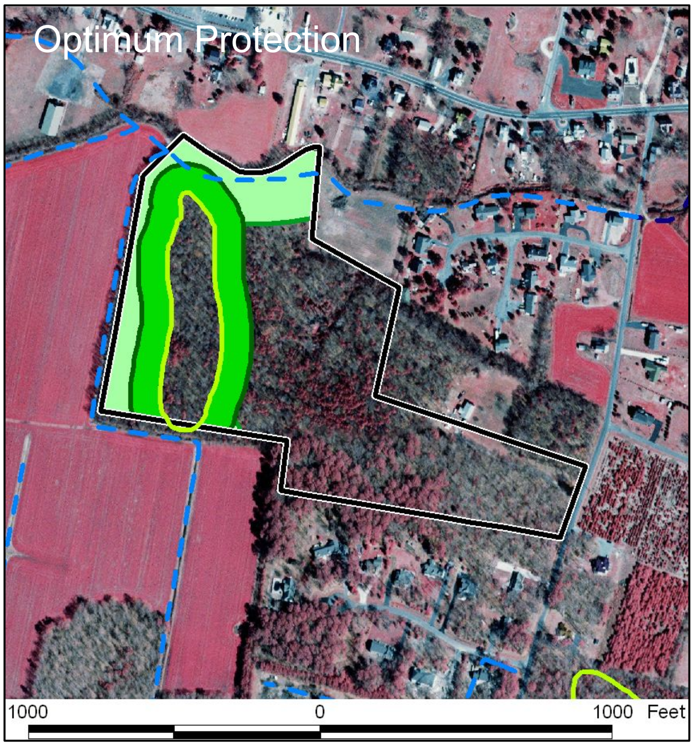
Small Residential Development in the Well Drained Region



Site Characteristics	
Site Acreage	23.7
Total Wetland Acreage	2.8
Nontidal Wetlands	2.8
Tidal Wetlands	0.0
Developable Acreage	20.9
Waterway length (ft)	1915.5
Stream Length	0.0
Ditch Length	1915.5
Minor Ditch Length	0.0
Fillable Ditch Length	0.0

Buffer Characteristics		
Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	4.7	7.1
Ac. on Ditches	2.9	5.9
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	3.4	4.1
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	1.6	2.9
Developable Acreage With Buffer	16.2	13.8
% Developable Acreage as Buffer	22.5	34.0
Acreage of Buffer to be Restored	0.0	0.0



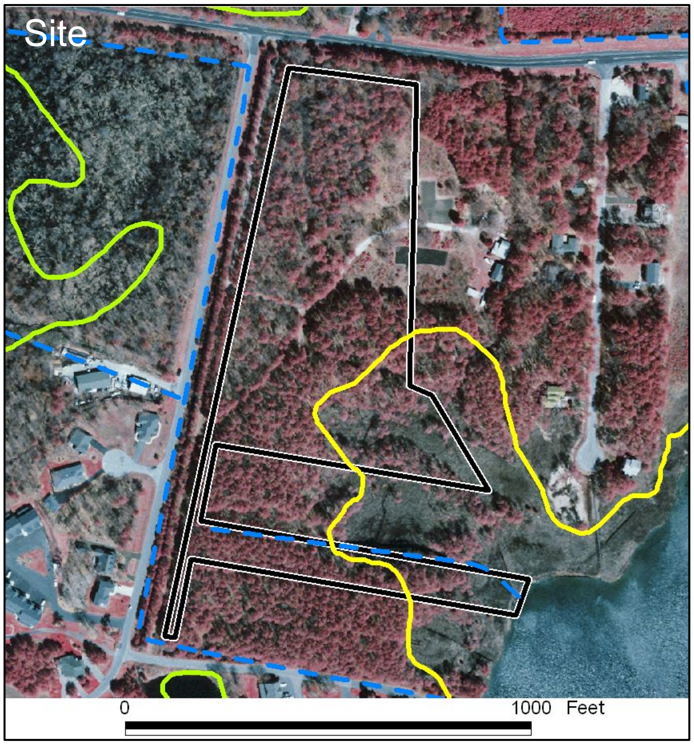


Development Outline
Tidal Waters
Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

Bethany Woods

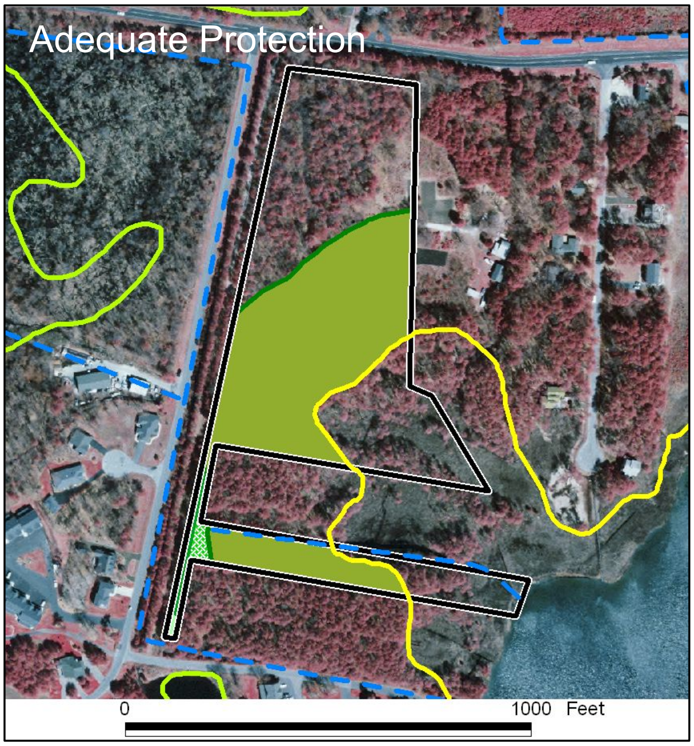
WDS2

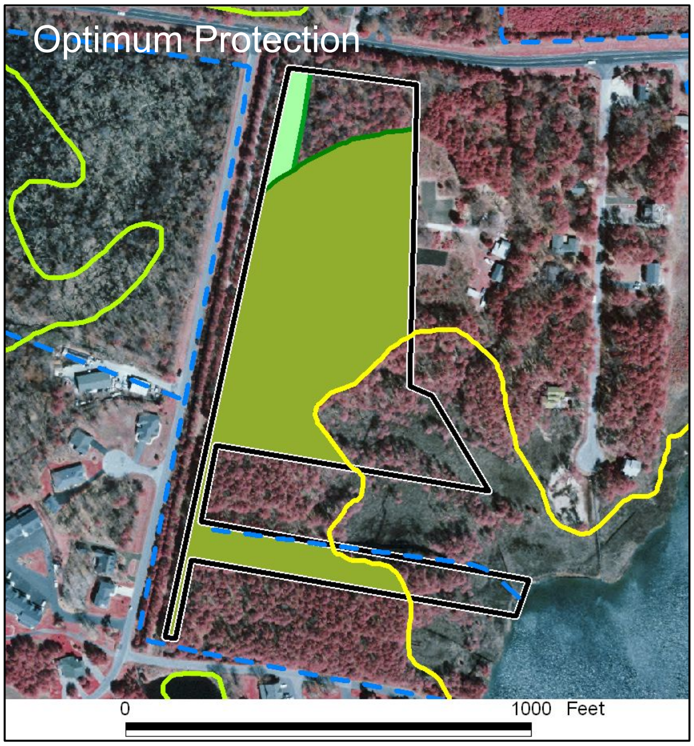
Small Residential Development in the Well Drained Region



Site Characteristics	
Site Acreage	11.6
Total Wetland Acreage	2.5
Nontidal Wetlands	0.0
Tidal Wetlands	2.5
Developable Acreage	9.1
Waterway length (ft)	2371.0
Stream Length	0.0
Ditch Length	1562.0
Minor Ditch Length	809.0
Fillable Ditch Length	809.0

Buffer Characteristics		
Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	5.5	8.1
Ac. on Ditches	0.1	1.9
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	0.0	0.0
Ac. on Tidal Wetlands	5.2	7.7
Ac. Confined by Buffer	0.2	0.0
Ac. Overlapping Buffers	0.1	1.5
Developable Acreage With Buffer	3.4	1.0
% Developable Acreage as Buffer	60.6	89.0
Acreage of Buffer to be Restored	0.0	0.0





━	Development Outline	⬭	Freshwater Wetlands	⬬	Tidal Buffer
━	Tidal Waters	⬭	Tidal Wetlands	▨	Areas isolated by buffer
━	Stream	⬬	Non-tidal Waterway Buffer		
╌	Filled Ditch	⬬	Freshwater Wetland Buffer		
╌	Ditch				

Savannah Square

WDS3

Small Commercial Development in the Well Drained Region

Site Characteristics	
Site Acreage	8.7
Total Wetland Acreage	0.0
Nontidal Wetlands	0.0
Tidal Wetlands	0.0
Developable Acreage	8.7
Waterway length (ft)	1358.0
Stream Length	0.0
Ditch Length	1358.0
Minor Ditch Length	1040.0
Fillable Ditch Length	1040.0

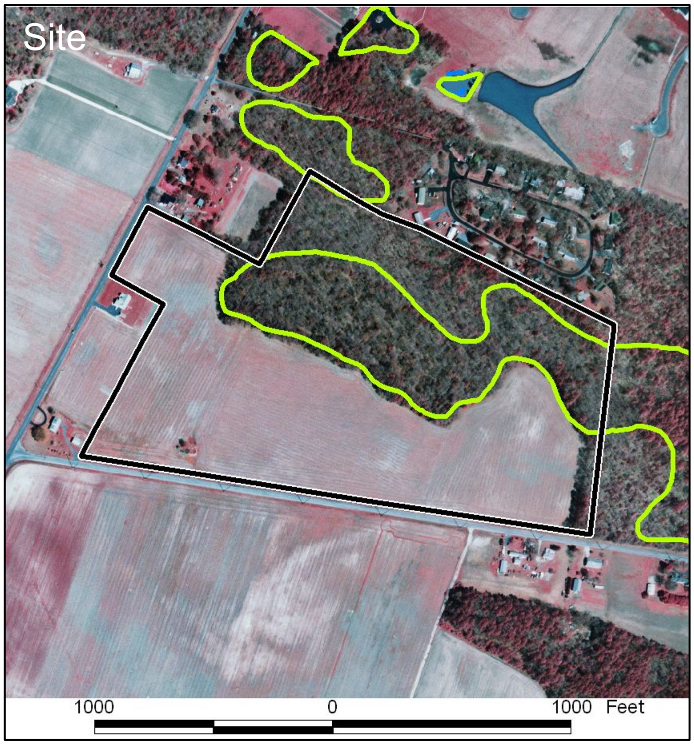
Buffer Characteristics		
Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	0.6	1.4
Ac. on Ditches	0.6	1.4
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	0.0	0.0
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	0.0	0.0
Developable Acreage With Buffer	8.1	7.3
% Developable Acreage as Buffer	6.7	16.1
Acreage of Buffer to be Restored	0.6	1.4

Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

Land of Givens

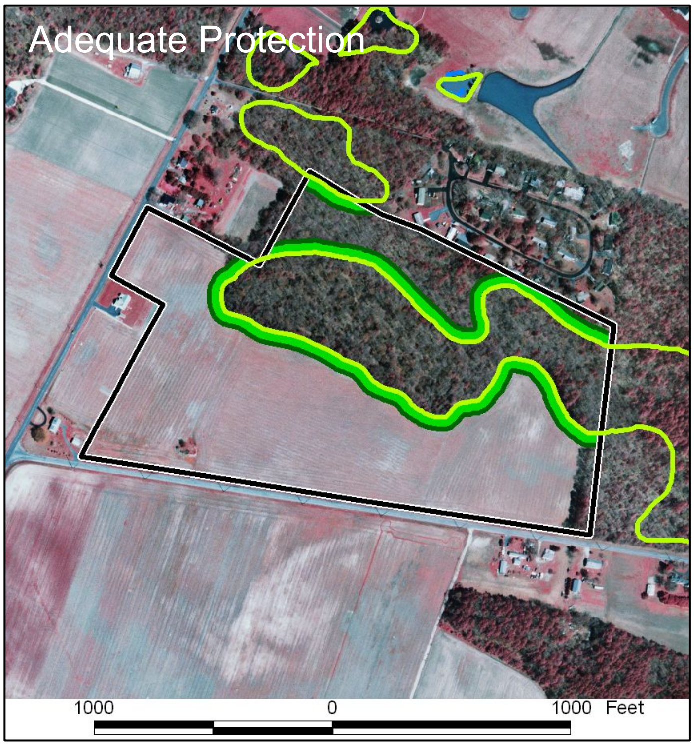
WDS4

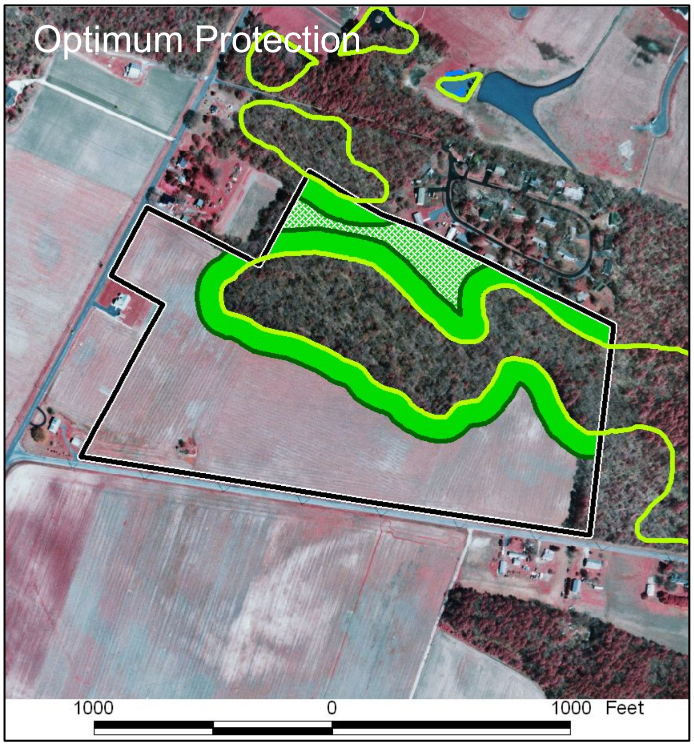
Small Residential Development in the Well Drained Region



Site Characteristics	
Site Acreage	50.2
Total Wetland Acreage	12.9
Nontidal Wetlands	12.9
Tidal Wetlands	0.0
Developable Acreage	37.1
Waterway length (ft)	0.0
Stream Length	0.0
Ditch Length	0.0
Minor Ditch Length	0.0
Fillable Ditch Length	0.0

Buffer Characteristics		
Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	5.1	12.3
Ac. on Ditches	0.0	0.0
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	5.1	10.0
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.0	2.3
Ac. Overlapping Buffers	0.0	0.0
Developable Acreage With Buffer	32.0	24.8
% Developable Acreage as Buffer	13.8	33.2
Acreage of Buffer to be Restored	1.8	4.4



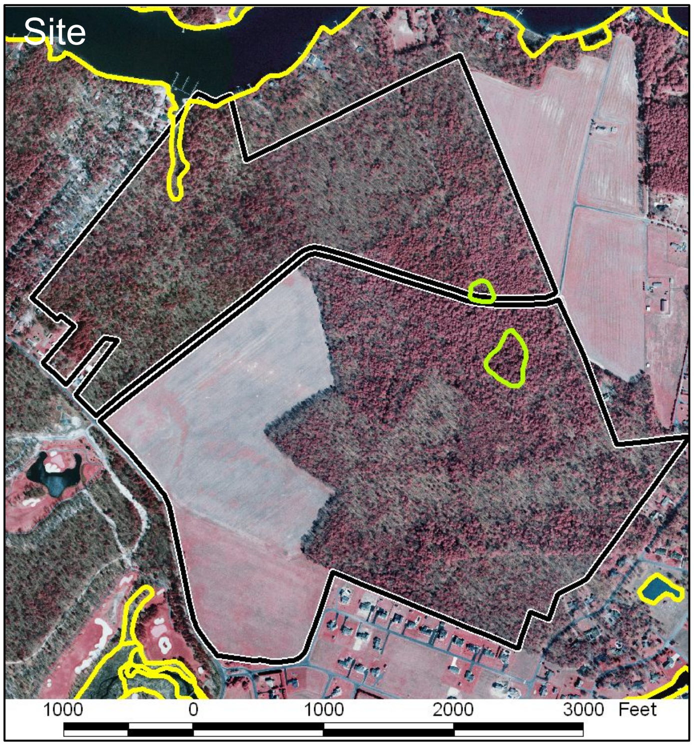


▬	Development Outline	⬭	Freshwater Wetlands	⬬	Tidal Buffer
▬	Tidal Waters	⬭	Tidal Wetlands	▨	Areas isolated by buffer
▬	Freshwater Stream	⬬	Non-tidal Waterway Buffer		
- - -	Filled Ditch	⬬	Freshwater Wetland Buffer		
- - -	Ditch				

Bridlewood

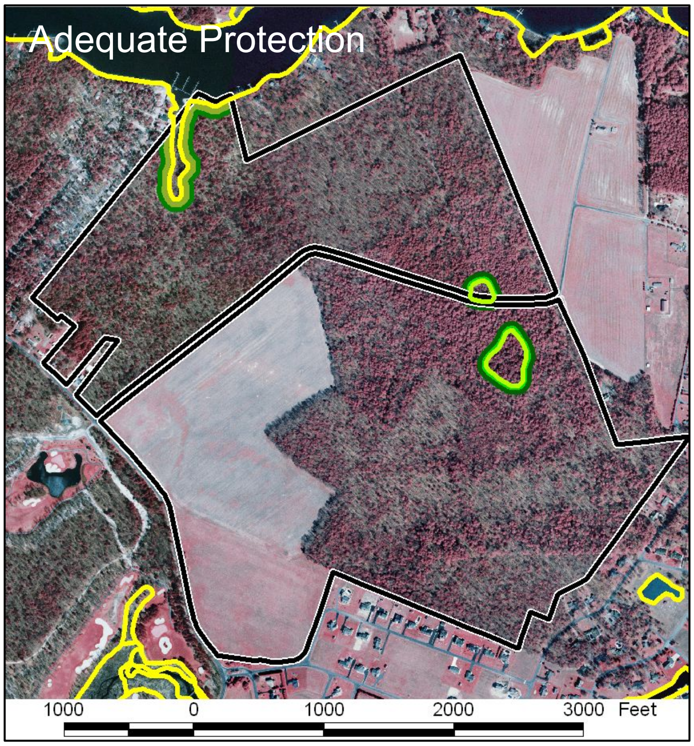
WDL1

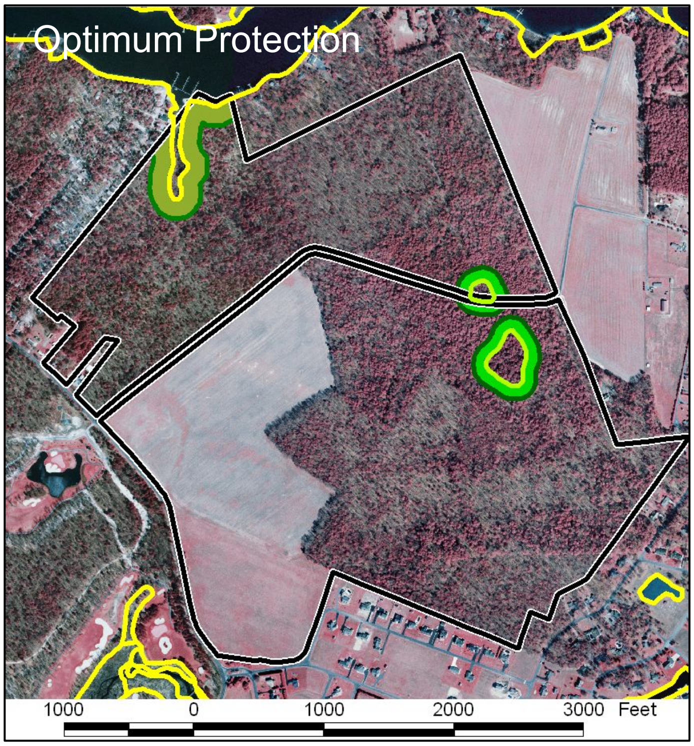
Large Residential Development in the Well Drained Region



Site Characteristics	
Site Acreage	314.0
Total Wetland Acreage	4.0
Nontidal Wetlands	2.5
Tidal Wetlands	1.5
Developable Acreage	308.7
Waterway length (ft)	0.0
Stream Length	0.0
Ditch Length	0.0
Minor Ditch Length	0.0
Fillable Ditch Length	0.0

Buffer Characteristics		
Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	5.7	11.5
Ac. on Ditches	0.0	0.0
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	2.1	5.0
Ac. on Tidal Wetlands	3.6	6.5
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	0.0	0.0
Developable Acreage With Buffer	303.1	297.2
% Developable Acreage as Buffer	1.8	3.7
Acreage of Buffer to be Restored	0.0	0.0





Development Outline
Tidal Waters
Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

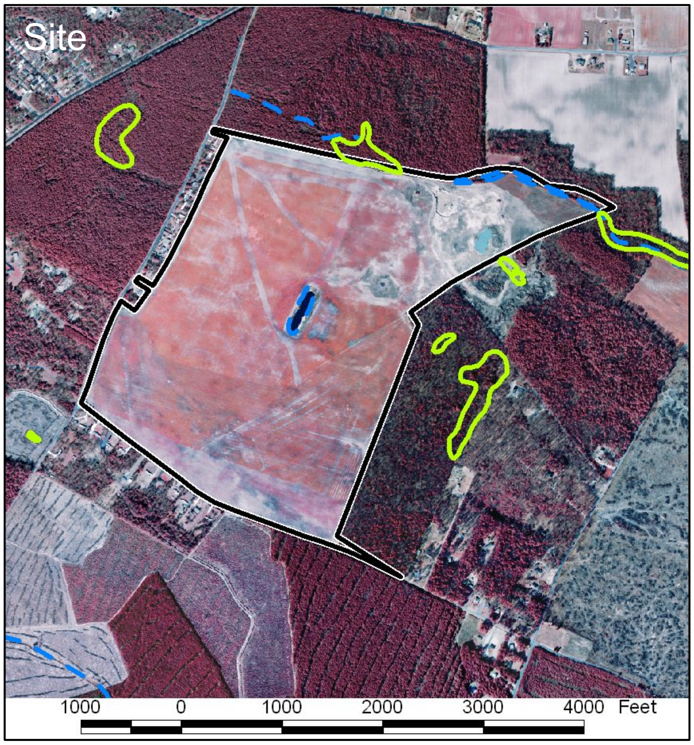
Avebury

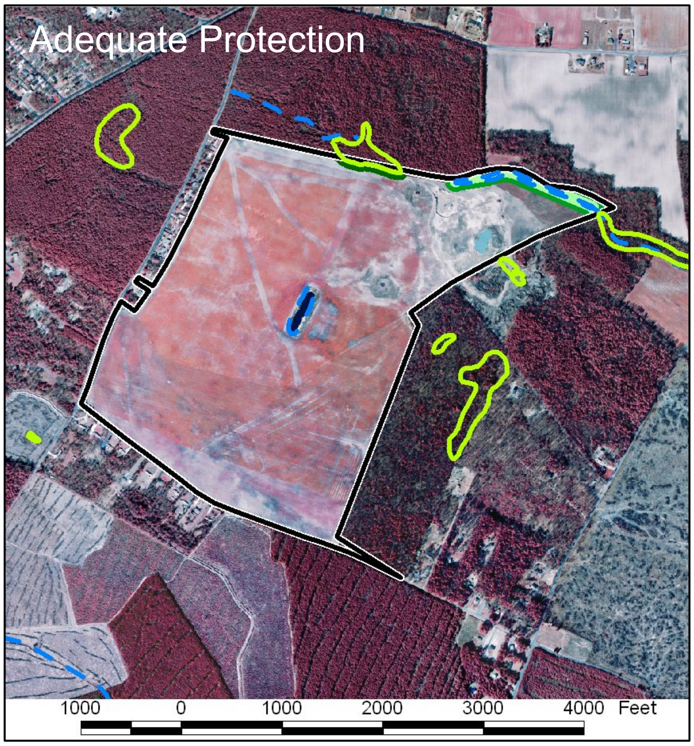
WDL2

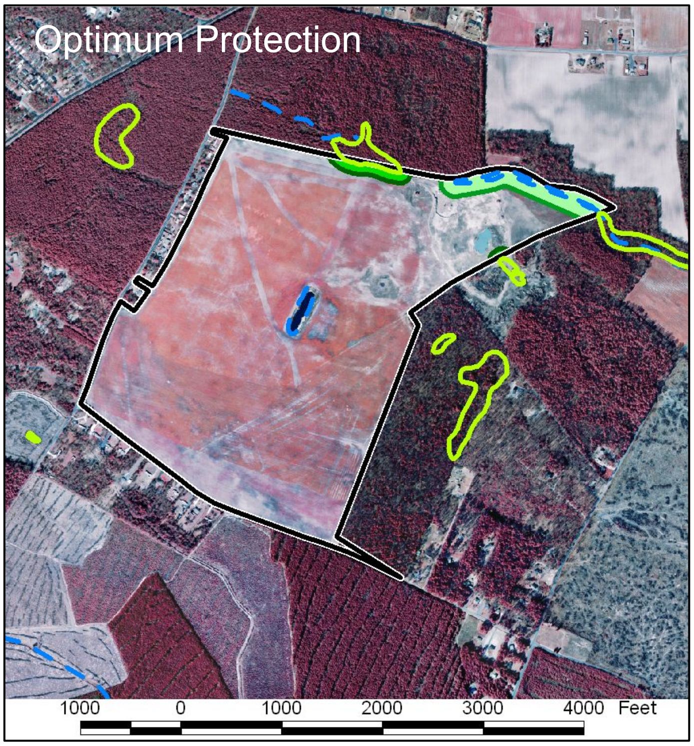
Large Residential Development in the Well Drained Region

Site Characteristics	
Site Acreage	32.9
Total Wetland Acreage	16.4
Nontidal Wetlands	16.4
Tidal Wetlands	0.0
Developable Acreage	16.5
Waterway length (ft)	2851.0
Stream Length	0.0
Ditch Length	2851.0
Minor Ditch Length	2291.0
Fillable Ditch Length	990.0

Buffer Characteristics		
Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	8.5	12.1
Ac. on Ditches	5.4	8.3
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	3.3	4.7
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.4	0.0
Ac. Overlapping Buffers	0.6	0.9
Developable Acreage With Buffer	8.0	4.4
% Developable Acreage as Buffer	51.5	73.3
Acreage of Buffer to be Restored	6.9	7.6



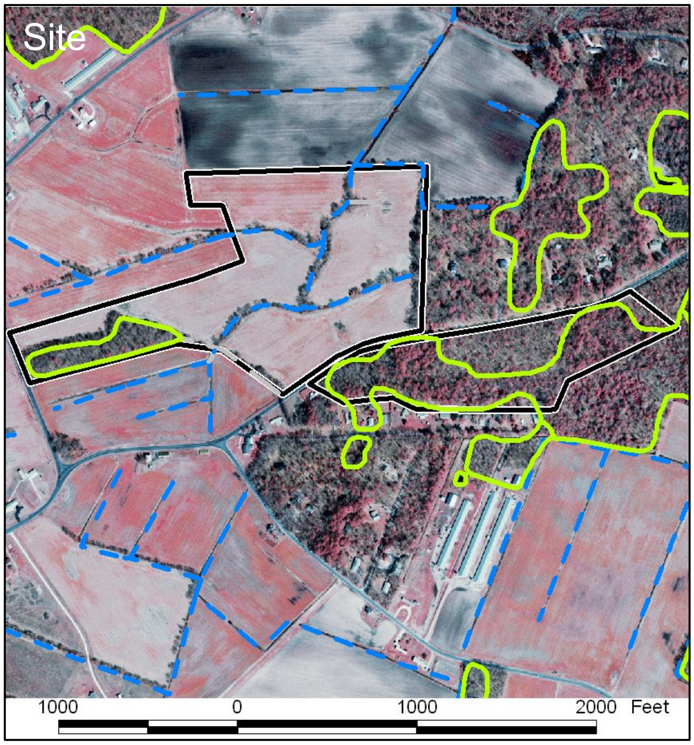




—	Development Outline	○	Freshwater Wetlands	●	Tidal Buffer
—	Tidal Waters	○	Tidal Wetlands	▨	Areas isolated by buffer
—	Freshwater Stream	●	Non-tidal Waterway Buffer		
- -	Filled Ditch	●	Freshwater Wetland Buffer		
- -	Ditch				

The Woodlands

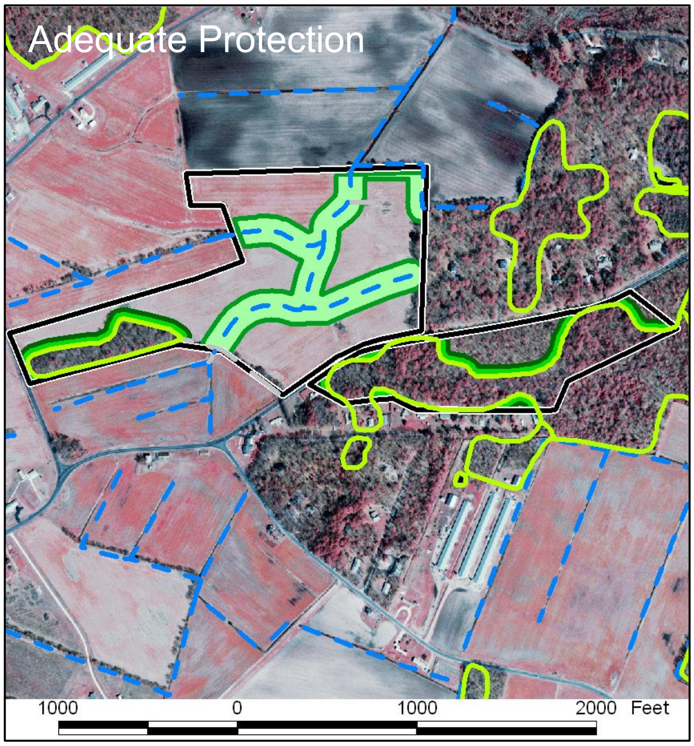
Small Residential Development in the Poorly Drained Region

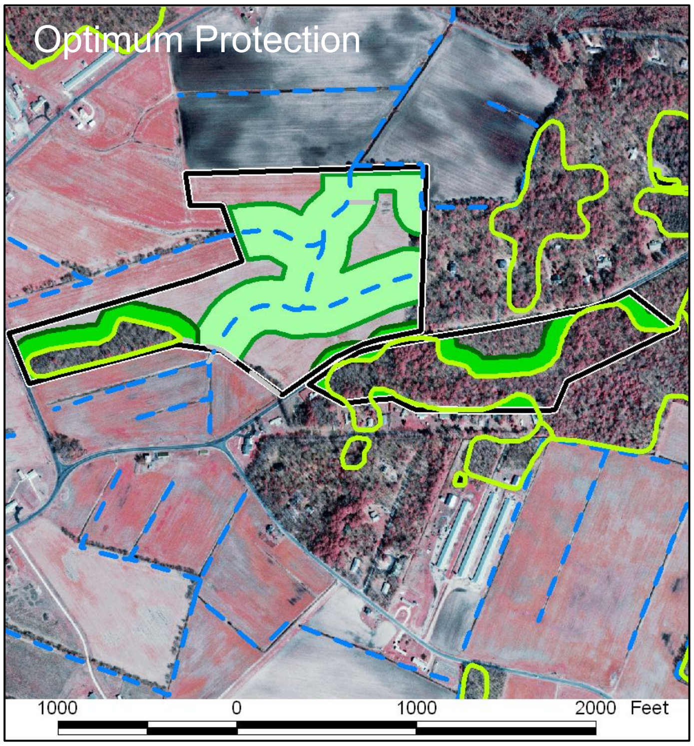


Site Characteristics	
Site Acreage	52.0
Total Wetland Acreage	12.5
Nontidal Wetlands	12.5
Tidal Wetlands	0.0
Developable Acreage	39.5
Waterway length (ft)	3362.0
Stream Length	0.0
Ditch Length	3362.0
Minor Ditch Length	2782.0
Fillable Ditch Length	799.0

Buffer Characteristics

Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	14.2	24.9
Ac. on Ditches	9.7	17.3
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	4.4	7.8
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	0.0	0.2
Developable Acreage With Buffer	25.3	14.6
% Developable Acreage as Buffer	35.9	63.0
Acreage of Buffer to be Restored	11.4	20.6





Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch

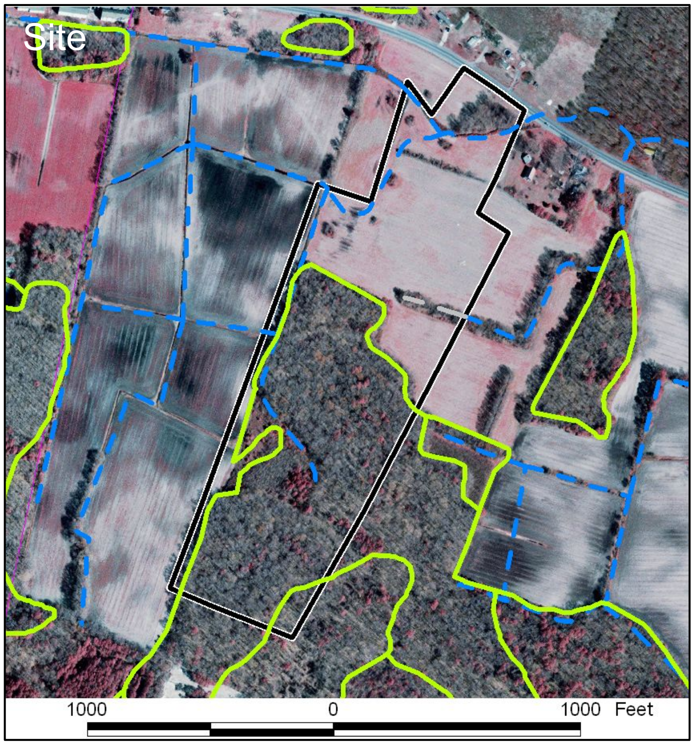
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer

Tidal Buffer
Areas isolated by buffer

Fenwick Medical Complex

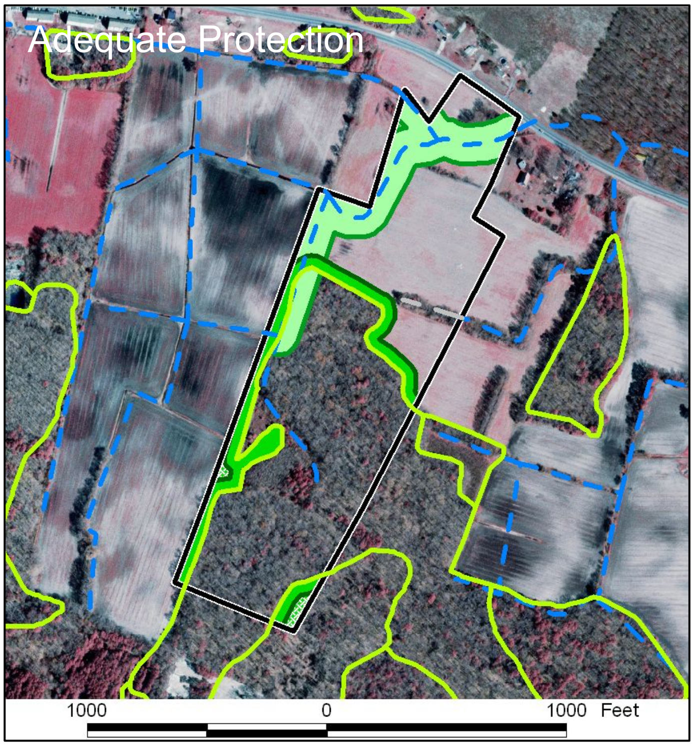
PDS2

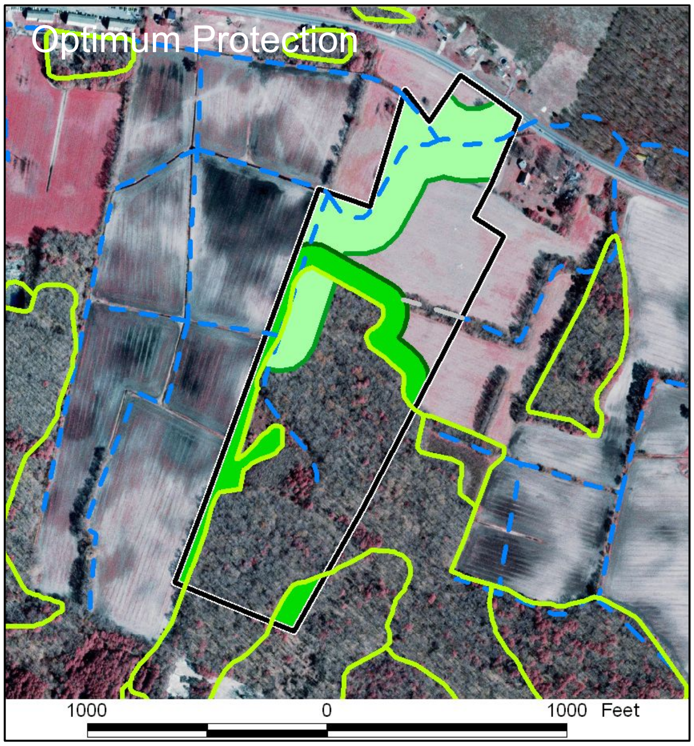
Small Commercial Development in the Poorly Drained Region



Site Characteristics	
Site Acreage	32.9
Total Wetland Acreage	16.4
Nontidal Wetlands	16.4
Tidal Wetlands	0.0
Developable Acreage	16.5
Waterway length (ft)	2851.0
Stream Length	0.0
Ditch Length	2851.0
Minor Ditch Length	2291.0
Fillable Ditch Length	990.0

Buffer Characteristics		
Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	8.5	12.1
Ac. on Ditches	5.4	8.3
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	3.3	4.7
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.4	0.0
Ac. Overlapping Buffers	0.6	0.9
Developable Acreage With Buffer	8.0	4.4
% Developable Acreage as Buffer	51.5	73.3
Acreage of Buffer to be Restored	6.9	7.6



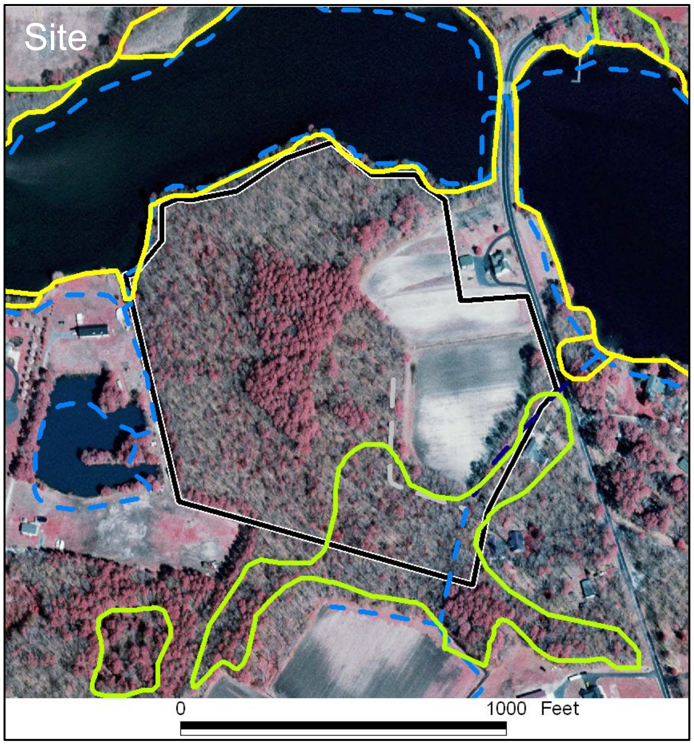


Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

Water’s Run

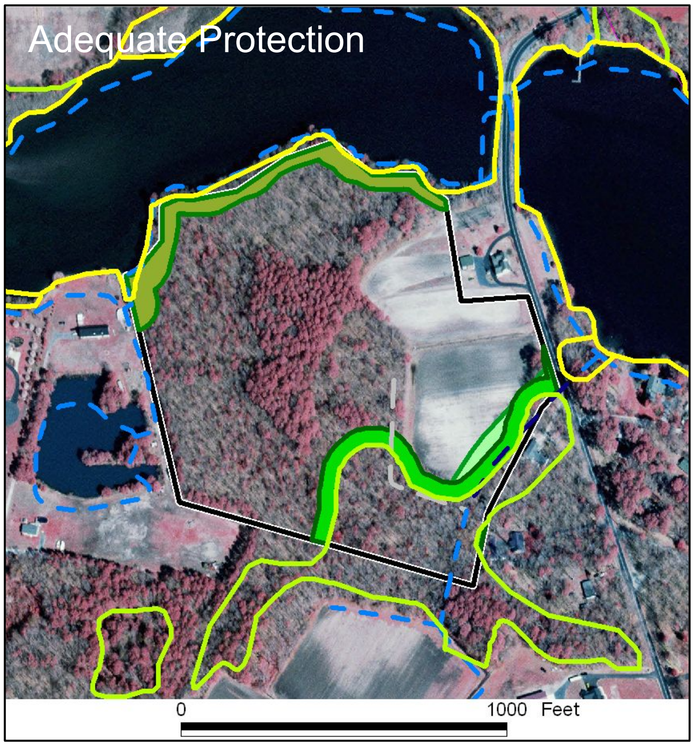
PDS3

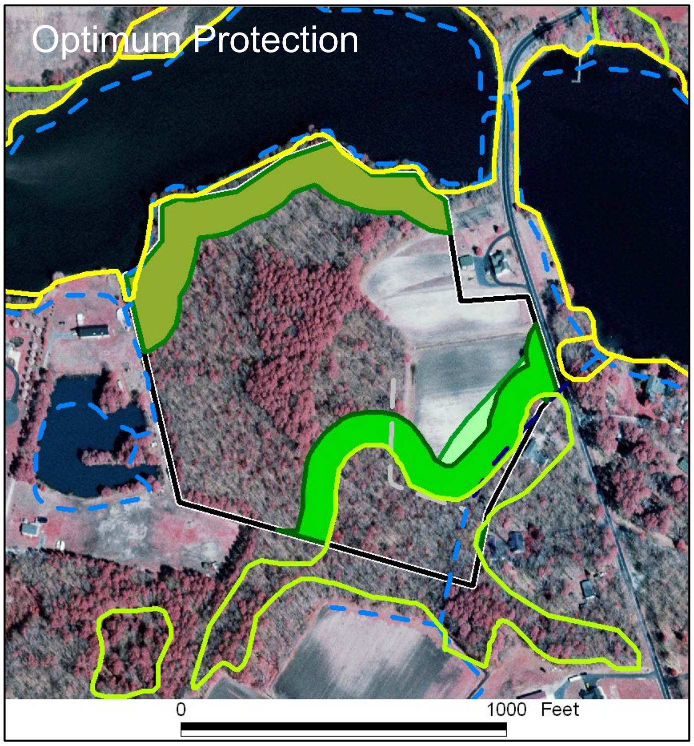
Small Residential Development in the Poorly Drained Region



Site Characteristics	
Site Acreage	27.2
Total Wetland Acreage	3.3
Nontidal Wetlands	3.2
Tidal Wetlands	0.0
Developable Acreage	23.9
Waterway length (ft)	389.0
Stream Length	150.0
Ditch Length	238.0
Minor Ditch Length	171.0
Fillable Ditch Length	171.0

Buffer Characteristics		
Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	3.2	6.9
Ac. on Ditches	0.0	0.0
Ac. on Streams	0.8	1.7
Ac. on Freshwater Wetlands	1.4	3.0
Ac. on Tidal Wetlands	1.5	3.6
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	0.6	1.5
Developable Acreage With Buffer	20.7	17.0
% Developable Acreage as Buffer	13.2	28.9
Acreage of Buffer to be Restored	0.4	1.4





Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch

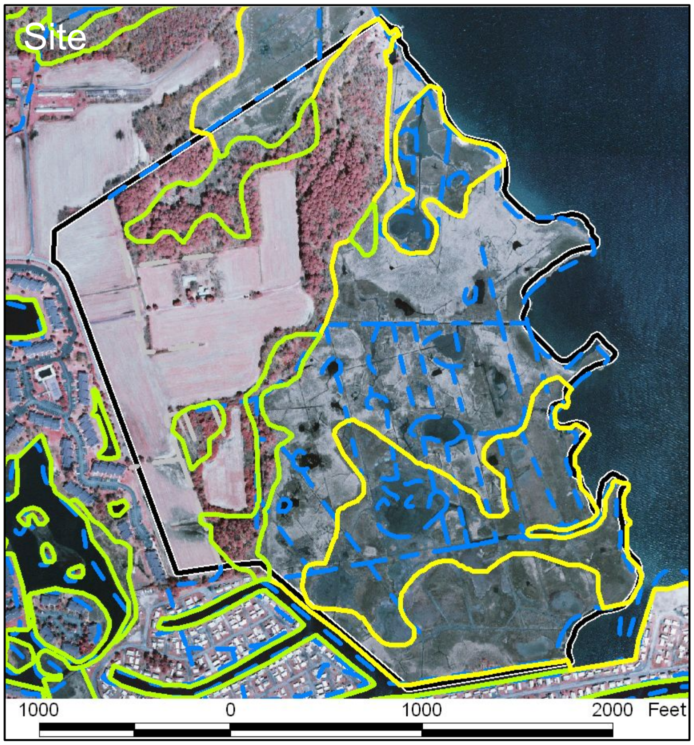
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer

Tidal Buffer
Areas isolated by buffer

Bayville Point

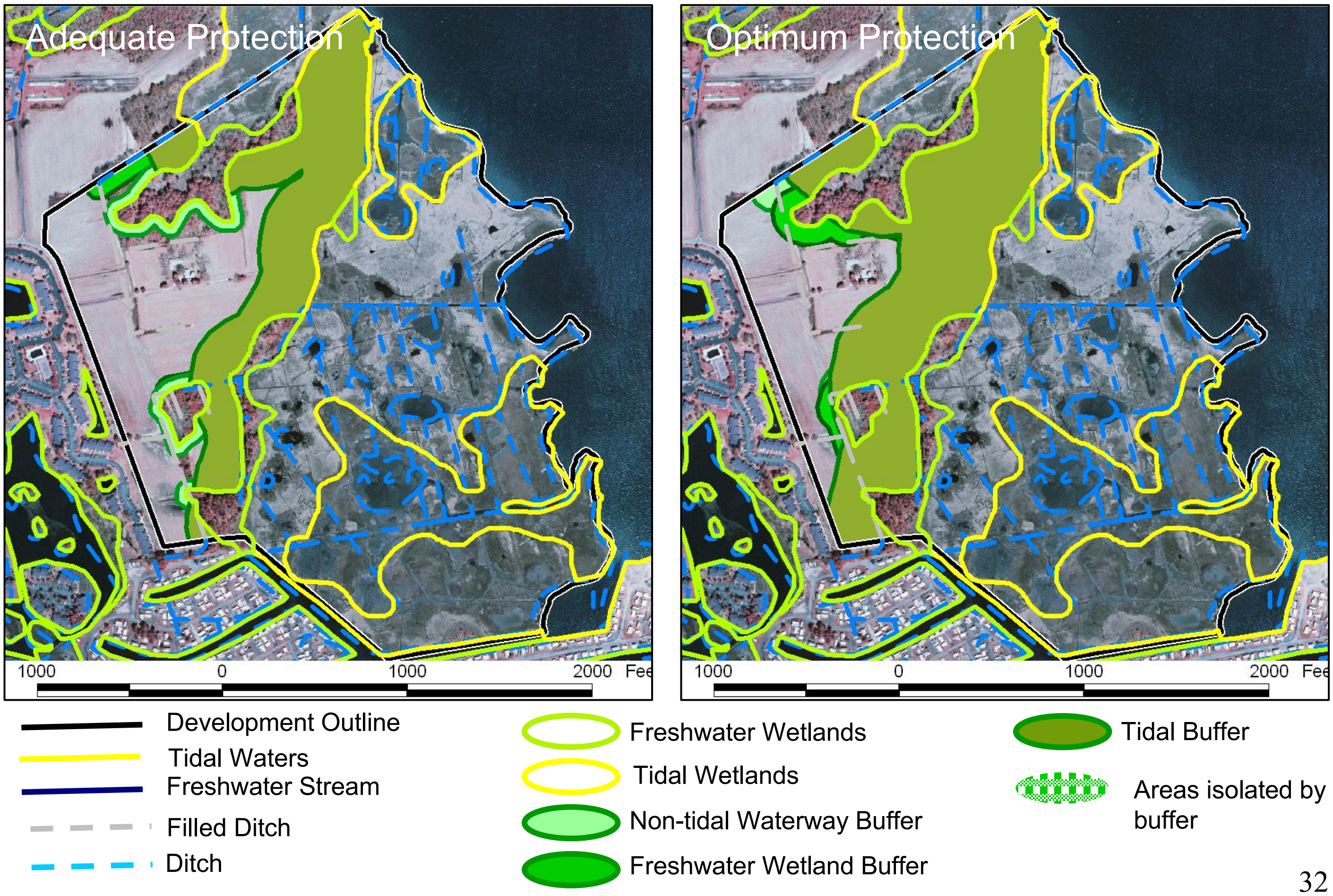
PDL1

Large Residential Development in the Poorly Drained Region



Site Characteristics	
Site Acreage	148.0
Total Wetland Acreage	99.7
Nontidal Wetlands	10.8
Tidal Wetlands	88.9
Developable Acreage	48.3
Waterway length (ft)	1653.0
Stream Length	0.0
Ditch Length	1653.0
Minor Ditch Length	1653.0
Fillable Ditch Length	972.0

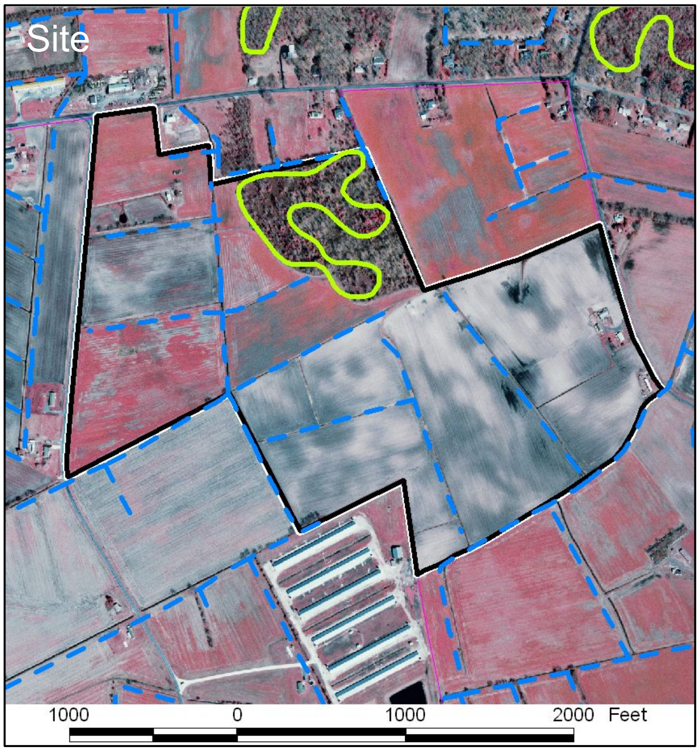
Buffer Characteristics		
Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	24.4	33.7
Ac. on Ditches	2.7	6.1
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	6.8	14.2
Ac. on Tidal Wetlands	20.9	31.1
Ac. Confined by Buffer	0.1	0.0
Ac. Overlapping Buffers	6.0	17.7
Developable Acreage With Buffer	23.9	14.6
% Developable Acreage as Buffer	50.5	69.8
Acreage of Buffer to be Restored	1.5	6.5



Barrington Park

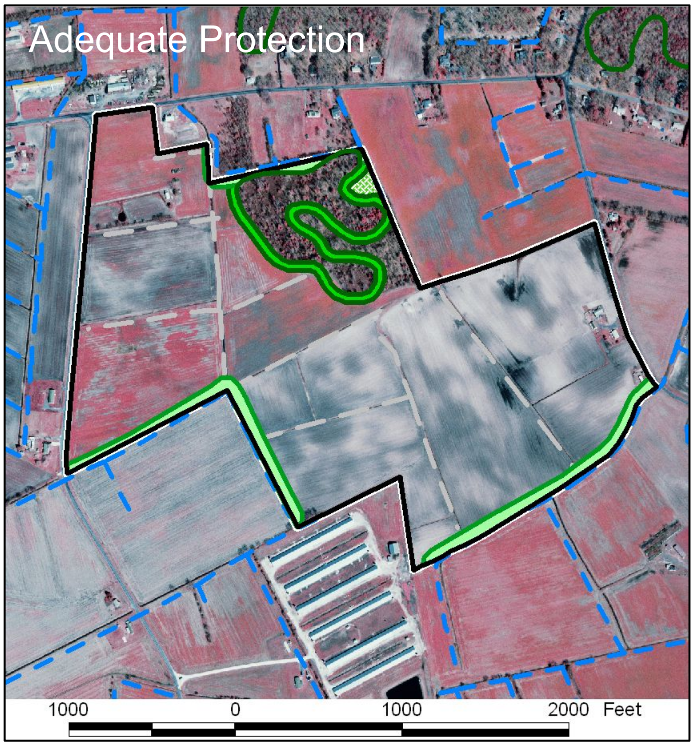
PDL2

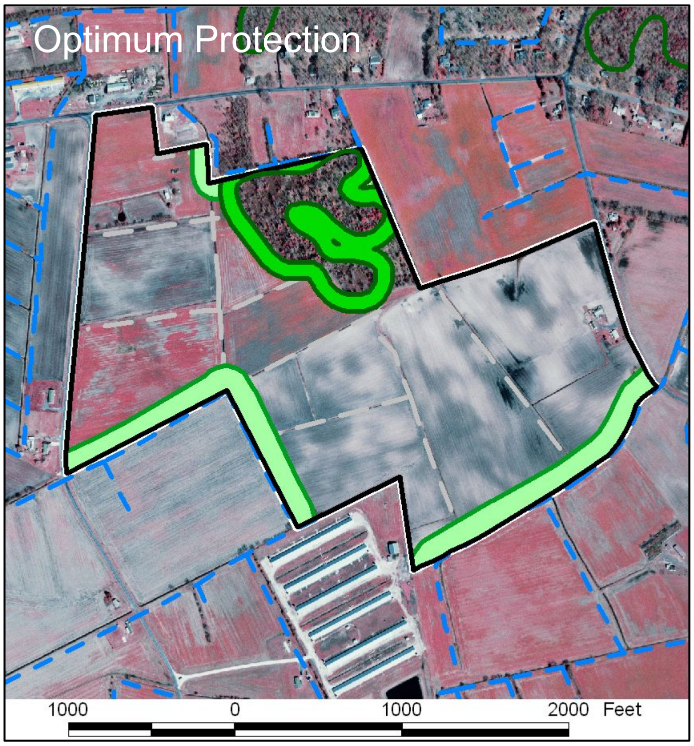
Large Residential Development in the Poorly Drained Region



Site Characteristics	
Site Acreage	128.0
Total Wetland Acreage	7.7
Nontidal Wetlands	7.7
Tidal Wetlands	0.0
Developable Acreage	120.3
Waterway length (ft)	2996.0
Stream Length	0.0
Ditch Length	2996.0
Minor Ditch Length	2996.0
Fillable Ditch Length	1993.0

Buffer Characteristics		
Protection Alternative	*Adequate*	*Optimum*
Acreage of Buffer	10.5	20.5
Ac. on Ditches	6.3	13.6
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	4.3	7.8
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.4	0.0
Ac. Overlapping Buffers	0.5	0.9
Developable Acreage With Buffer	109.8	99.8
% Developable Acreage as Buffer	8.7	17.0
Acreage of Buffer to be Restored	6.5	14.9





▬ Development Outline
▬ Tidal Waters
▬ Freshwater Stream
- - Filled Ditch
- - Ditch

○ Freshwater Wetlands
○ Tidal Wetlands
● Non-tidal Waterway Buffer
● Freshwater Wetland Buffer

● Tidal Buffer
▨ Areas isolated by buffer

Table 8. Site characteristics by watershed hydrogeomorphic region. Five sites are in the Poorly Drained and six are in the Well Drained Region.

	Poorly Drained				Well Drained			
Site Characteristics	Min	Max	Mean	Median	Min	Max	Mean	Median
Site Acreage	27.2	148.0	77.6	52.0	8.7	314.0	107.7	37.0
Total Wetland Acreage	3.3	99.7	27.9	12.5	0.0	12.9	4.0	2.7
Nontidal Wetlands	3.2	16.4	10.1	10.8	0.0	12.9	3.3	2.1
Tidal Wetlands	0.0	88.9	17.8	0.0	0.0	2.5	0.7	0.0
Developable Acreage	16.5	120.3	49.7	39.5	8.7	308.7	103.4	29.0
Waterway length (ft)	389.0	3362.0	2250.2	2851.0	0.0	2371.0	1085.6	1113.5
Stream Length	0.0	150.0	50.0	0.0	0.0	0.0	0.0	0.0
Ditch Length	238.0	3362.0	2220.0	2851.0	0.0	1915.5	805.9	679.0
Minor Ditch Length	171.0	2996.0	1784.2	2291.0	0.0	1040.0	308.2	0.0
Fillable Ditch Length	171.0	1993.0	985.0	972.0	0.0	1040.0	308.2	0.0

Buffer Characteristics. The percentage of developable acreage as buffer varied widely for both protection alternatives (Table 10). The median percentage of developable acreage as buffer for the adequate protection alternative was 13.8% and this ranged from 1.8% to 60.6%. For the optimum protection alternative the median was 33.2% with a range of 3.7% to 89%. The total buffer acreage was evenly distributed between buffers on ditches, freshwater wetlands, and tidal areas. Sites of the Poorly Drained Region had more developable area as buffer (32% for the adequate alternative) than did sites of the Well Drained Region (18%) (Table 11). Small developments had about twice as much of their developable acreage as buffer than did larger sites (Table 12). The two sites with tidal wetlands adjacent to gradually sloping uplands had two of the three greatest percentages of developable area as buffer. Acreage of buffer requiring restoration to forest was generally low with a mean acreage of 2.6 for the adequate protection alternative and 5.2 for the optimum protection alternative (Table 10).

Table 9. Site characteristics by development size. Seven sites are small (< 61 acres) and four sites are large (>61 acres).

	Small				Large			
Site Characteristics	Min	Max	Mean	Median	Min	Max	Mean	Median
Site Acreage	8.7	52.0	29.5	27.2	128.0	314.0	207.0	193.0
Total Wetland Acreage	0.0	16.4	7.2	3.3	1.8	99.7	28.3	5.8
Nontidal Wetlands	0.0	16.4	6.8	3.2	1.8	10.8	5.7	5.1
Tidal Wetlands	0.0	2.5	0.4	0.0	0.0	88.9	22.6	0.8
Developable Acreage	8.7	39.5	22.2	20.9	48.3	308.7	178.4	178.3
Waterway length (ft)	0.0	3362.0	1749.5	1915.5	0.0	2996.0	1379.5	1261.0
Stream Length	0.0	150.0	21.4	0.0	0.0	0.0	0.0	0.0
Ditch Length	0.0	3362.0	1612.4	1562.0	0.0	2996.0	1162.3	826.5
Minor Ditch Length	0.0	2782.0	1013.3	809.0	0.0	2996.0	919.3	340.5
Fillable Ditch Length	0.0	1040.0	544.1	799.0	0.0	1993.0	741.3	486.0

Discussion.

This analysis clearly shows that the amount of buffer required to maximize the protection of water resources is highly variable among developments. This variation is driven by the underlying differences in the type, amount, and distribution of wetlands and waterways on a development. Smaller developments, developments in the Poorly Drained Region, and developments with tidal wetlands adjacent to gradually sloping uplands will have more buffer area. Larger developments and developments in the Well Drained Region will have less buffer area. For adequate and consistent resource protection, buffer acreage on a development must vary in response to the number and distribution of water features present, and thus a buffer regulation will not compel even responsibility for buffering among developments,.which are inherently variable in their water features. On average, buffers of both protection alternatives fell within the range of Sussex County open space requirements for development (~25 – 40%). For the adequate alternative, lumping buffer and nontidal wetland acreage amounted to 32% of a development eligible for inclusion as open space; still within the range of County requirements. Tidal wetlands are not eligible for inclusion as open space, and only some developments include freshwater wetlands as open space. At writing, the County was considering removal of freshwater wetlands from inclusion in open space calculations (*personal communication* Lawrence Lank, Sussex County Planning and Zoning).

Table 10. Buffer characteristics by protection alternatives.

	SUFFICIENT				**OPTIMUM**			
Buffer Characteristics	Min	Max	Mean	Median	Min	Max	Mean	Median
Acreage of Buffer	0.6	24.4	8.0	5.7	1.4	33.7	13.5	11.5
Ac. on Ditches	0.0	9.7	2.5	0.6	0.0	17.3	5.0	1.9
Ac. on Natural Waterways	0.0	4.7	0.5	0.0	0.0	7.6	0.8	0.0
Ac. on Freshwater Wetlands	0.0	6.8	2.9	3.3	0.0	14.2	5.3	4.7
Ac. on Tidal Wetlands	0.0	20.9	2.8	0.0	0.0	31.1	4.4	0.0
Ac. Confined by Buffer	0.0	0.4	0.1	0.0	0.0	2.3	0.2	0.0
Ac. Overlapping Buffers	0.0	6.0	0.9	0.1	0.0	17.7	2.3	0.9
Developable Acreage With Buffer	3.4	303.1	71.0	23.9	1.0	297.2	65.5	14.6
% Developable Acreage as Buffer	1.8	60.6	24.3	13.8	3.7	89.0	39.3	33.2
Acreage of Buffer to be Restored	0.0	11.4	2.6	0.6	0.0	20.6	5.2	1.4

For certain developments, requiring buffers will result in a greatly reduced area on which to build. This will be most pronounced in the Poorly Drained Region where tidal wetlands are present. Bayville Point (PDL1) is a good example of this case (page 32). Here buffers take up 50.5% and 69.8% of the developable area for the two alternatives. The majority of the buffer acreage is of tidal wetlands. Development on this location will result in particularly large resource impacts because it lies in the path of rapidly migrating wetlands. At application to PLUS, Bayville Point was a proposed residential planned community of 242 units. To maintain this number of units with buffers that provide optimum protection, greater than 17 units per acre would be required.

Small developments had about twice as much of their developable acreage as buffer than did larger developments. The Woodlands (PDS1) (page 29) is a good example of a small development in the Poorly Drained Region where buffers of both adequate and optimum protection would alter site design..

Table 11. Buffer characteristics by protection alternative and hydrogeomorphic region for eleven randomly selected sites.

	ADEQUATE								OPTIMUM							
	Poorly Drained				Well Drained				Poorly Drained				Well Drained			
Buffer Characteristics	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median
Acreage of Buffer	3.2	24.4	12.2	10.5	0.6	5.9	4.6	5.3	6.9	33.7	19.6	20.5	1.4	12.3	8.4	8.9
Ac. on Ditches	0.0	9.7	4.8	5.4	0.0	2.9	0.6	0.1	0.0	17.3	9.1	8.3	0.0	5.9	1.5	0.7
Ac. on Natural Waterways	0.0	0.8	0.2	0.0	0.0	4.7	0.8	0.0	0.0	1.7	0.3	0.0	0.0	7.6	1.3	0.0
Ac. on Freshwater Wetlands	1.4	6.8	4.0	4.3	0.0	5.1	1.9	1.5	3.0	14.2	7.5	7.8	0.0	10.0	3.5	3.2
Ac. on Tidal Wetlands	0.0	20.9	4.5	0.0	0.0	5.2	1.5	0.0	0.0	31.1	6.9	0.0	0.0	7.7	2.4	0.0
Ac. Confined by Buffer	0.0	0.4	0.2	0.1	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.4	0.0
Ac. Overlapping Buffers	0.0	6.0	1.5	0.6	0.0	1.6	0.3	0.0	0.2	17.7	4.2	0.9	0.0	2.9	0.7	0.0
Developable Acreage With Buffer	8.0	109.8	37.5	23.9	3.4	303.1	98.8	24.1	4.4	99.8	30.1	14.6	1.0	297.2	95.1	19.3
% Developable Acreage as Buffer	8.7	51.5	32.0	35.9	1.8	60.6	18.0	10.2	17.0	73.3	50.4	63.0	3.7	89.0	30.0	24.6
Acreage of Buffer to be Restored	0.4	11.4	5.3	6.5	0.0	1.8	0.4	0.0	1.4	20.6	10.2	7.6	0.0	4.4	1.0	0.0

Table 12. Buffer characteristics by protection alternative and development size for eleven randomly selected sites. Large developments are <61 acres, small are >61 acres.

	ADEQUATE								OPTIMUM							
	Large				Small				Large				Small			
Buffer Characteristics	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median
Acreage of Buffer	5.7	24.4	11.6	8.2	0.6	14.2	6.0	5.1	9.8	33.7	18.9	16.0	1.4	24.9	10.4	8.1
Ac. on Ditches	0.0	6.3	2.2	1.3	0.0	9.7	2.7	0.6	0.0	13.6	4.9	3.1	0.0	17.3	5.0	1.9
Ac. on Natural Waterways	0.0	4.7	1.2	0.0	0.0	0.8	0.1	0.0	0.0	7.6	1.9	0.0	0.0	1.7	0.2	0.0
Ac. on Freshwater Wetlands	0.9	6.8	3.5	3.2	0.0	5.1	2.5	3.3	2.2	14.2	7.3	6.4	0.0	10.0	4.2	4.1
Ac. on Tidal Wetlands	0.0	20.9	6.1	1.8	0.0	5.2	1.0	0.0	0.0	31.1	9.4	3.3	0.0	7.7	1.6	0.0
Ac. Confined by Buffer	0.0	0.4	0.2	0.2	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.3	0.0
Ac. Overlapping Buffers	0.0	6.0	1.6	0.3	0.0	1.6	0.4	0.1	0.0	17.7	4.7	0.4	0.0	2.9	1.0	0.9
Developable Acreage With Buffer	23.9	303.1	166.8	170.1	3.4	32.0	16.2	16.2	14.6	297.2	159.5	163.1	1.0	24.8	11.8	13.8
% Developable Acreage as Buffer	1.8	50.5	15.9	5.6	6.7	60.6	29.2	22.5	3.7	69.8	23.7	10.6	16.1	89.0	48.2	34.0
Acreage of Buffer to be Restored	0.0	6.5	2.0	0.8	0.0	11.4	3.0	0.6	0.0	14.9	5.4	3.3	0.0	20.6	5.1	1.4

Nearly one quarter of the property was wetlands and the site was criss-crossed by ditches, most of which appeared unable to be disconnected from the drainage network. The percent developable acreage was 35.9% and 63.0% for the two protection alternatives. About two-thirds of the buffer acreage was of the ditches. The Woodlands was a proposed community of 88 units. To maintain this number of units with buffers that provide adequate protection, greater than 2.5 units per acre would be required. This density still falls within what is currently permitted by the County.

Buffers of ditches made up a large portion of total buffer acreage, even after half of minor ditches were removed from the drainage network. Ditches receive inputs of both surface water and groundwater [92], and are important conduits for nitrogen, phosphorus, and sediments [93]. However, many ditches are shallow (~ ≤ 2 – 3 feet deep) and are fed primarily by localized inputs of surface water [94]. These shallow ditches may receive less benefit from buffers than deeper ditches (> 2 – 3 feet deep) [94]. Shallow ditches also provide lower levels of other wetland functions relative to natural wetlands and waterways. Reducing the minimum buffer width on shallow ditches could provide the flexibility needed by developers to site homes and more adequately buffer wetlands and more functionally important waterways.

Using The Woodlands (PDS1 page 29) as an example, the developable acreage as buffer was reduced from 35.9% to 26% by requiring 40 foot buffers on shallow ditches[8]. This strategy will substantially reduce the average % developable area as buffer for both protection alternatives.

Buffers on shallow ditches should not fall below 35 feet (*see Width above*), and should remain forested. Forested buffers of ditches result in lower nutrient inputs and an increased capacity of ditches to slow or reduce pollutants [95]. In light of the fact that ditches remain the dominant waterways even after site development, it is recommended that 1) governments encourage cooperation within and between developments to reduce ditch networks through fill and conversion to stormwater features while continuing to manage for adequate drainage and 2) incentives be developed which take advantage of the opportunity that development provides to address the drainage network by encouraging practices that further improve nutrient reduction in ditches. These practices include channel regrading to simulate flood plains, small scale controlled drainage, and in-line wetlands [96-98].

Both protection alternatives resulted in low acreages and costs for required buffer restoration. Recommended restoration practices for buffers are detailed in the August 2006 version of the PCS [7]. The cost to install Conservation Reserve Enhancement Program (CREP) forested buffers range from $125 -- $725/acre. Since buffers installed in developments often use better quality plant material than typical CREP projects, a cost of $1,000/acre is applied here. This results in an average of $2,600 to $5,200 in restoration costs per development.

This study suggests that most developments in the Well Drained Region can accommodate buffers of the optimum protection alternative as required open space. Example developments in this regard include Bridlewood (WDL1 page 27) and Savannah Square (WDS3 page 25). Some small developments and developments in the Poorly Drained Region will have to substantially adapt site designs to accommodate buffers. Adaptations could include smaller lot sizes, smaller street widths, alternative parking options, and perhaps increased densities. Cooperation of Sussex County to develop ordinances that facilitate flexible site designs will be critical to developments accommodating buffers. Where buffer extent must be reduced, shallow ditches should be addressed first, followed by flats and depressional wetlands.

Additional Recommendations

Review of the buffer system analysis has led to following additional recommendations.

1. Given the level and type of development already permitted along Bay shorelines, given that this development has been permitted without pollution control strategy requirements and without adequate buffers, and given that sea level rise and tidal wetland migration is predicted to increase, perhaps drastically[99-101][9], it is recommended that the optimum protection alternative be afforded to tidal waters and wetlands.

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[8] For adequate protection alternative. Assumed, based on study data layers, that 2,119 feet or 83% of these ditches on site were shallow.

[9] Recent information suggests that sea-level rise has a high probability of increasing rapidly over the next 100 years such that sea-level could be 45 to 145 cm higher by 2100. These increases in the rates of sea level rise will increase rates of wetland migration inland. Furthermore, increased stresses on tidal wetlands are placing greater importance on their capacity to migrate inland to maintain themselves (*see citations in text above*).

2. Buffers of any wetlands and waterways that occur on adjacent undeveloped properties and that have more than half of their buffer width on the developing property should be required on the developing property.
3. Shallow ditches can be afforded smaller buffer widths, not to fall below 35 feet, so that buffers of natural wetlands and waterway features can be better accommodated.
4. Governments should encourage cooperation within and among developments to reduce ditch networks and implement additional nutrient reduction techniques in remaining ditches.
5. Ordinances and incentives that facilitate development site designs to accommodate buffers are likely critical for implementing a watershed level buffer system.

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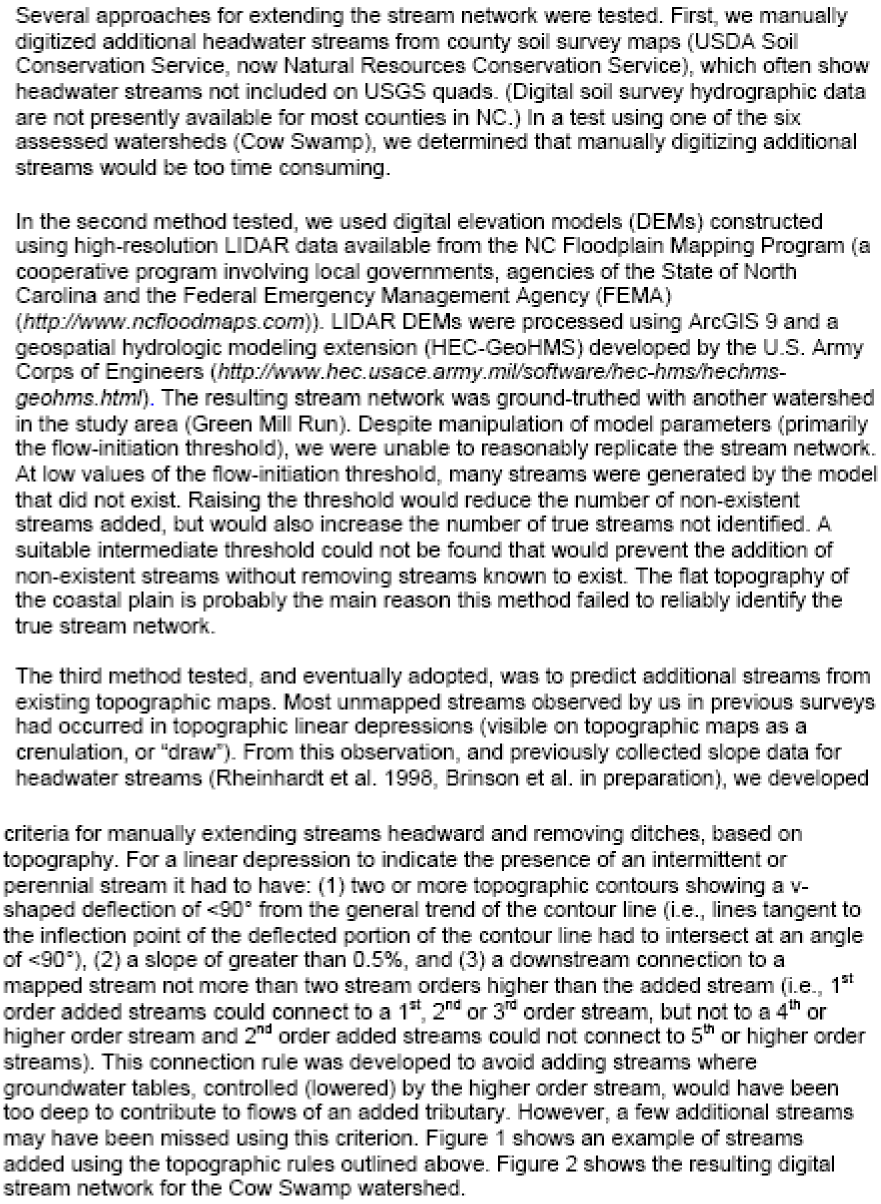
Appendix 1: Excerpt from Rheinhardt et al. 2005 detailing an approach to mapping unmapped natural headwaters. From Rheinhardt, R.D., et al., Applying Ecological Assessments to Planning Stream Restorations in Coastal Plain North Carolina. 2005, North Carolina Department of Environment and Natural Resources: Raleigh, NC. p. 39.



Several approaches for extending the stream network were tested. First, we manually digitized additional headwater streams from county soil survey maps (USDA Soil Conservation Service, now Natural Resources Conservation Service), which often show headwater streams not included on USGS quads. (Digital soil survey hydrographic data are not presently available for most counties in NC.) In a test using one of the six assessed watersheds (Cow Swamp), we determined that manually digitizing additional streams would be too time consuming.

In the second method tested, we used digital elevation models (DEMs) constructed using high-resolution LIDAR data available from the NC Floodplain Mapping Program (a cooperative program involving local governments, agencies of the State of North Carolina and the Federal Emergency Management Agency (FEMA) (*http://www.ncfloodmaps.com*)). LIDAR DEMs were processed using ArcGIS 9 and a geospatial hydrologic modeling extension (HEC-GeoHMS) developed by the U.S. Army Corps of Engineers (*http://www.hec.usace.army.mil/software/hec-hms/hechms-geohms.html*). The resulting stream network was ground-truthed with another watershed in the study area (Green Mill Run). Despite manipulation of model parameters (primarily the flow-initiation threshold), we were unable to reasonably replicate the stream network. At low values of the flow-initiation threshold, many streams were generated by the model that did not exist. Raising the threshold would reduce the number of non-existent streams added, but would also increase the number of true streams not identified. A suitable intermediate threshold could not be found that would prevent the addition of non-existent streams without removing streams known to exist. The flat topography of the coastal plain is probably the main reason this method failed to reliably identify the true stream network.

The third method tested, and eventually adopted, was to predict additional streams from existing topographic maps. Most unmapped streams observed by us in previous surveys had occurred in topographic linear depressions (visible on topographic maps as a crenulation, or “draw”). From this observation, and previously collected slope data for headwater streams (Rheinhardt et al. 1998, Brinson et al. in preparation), we developed criteria for manually extending streams headward and removing ditches, based on topography. For a linear depression to indicate the presence of an intermittent or perennial stream it had to have: (1) two or more topographic contours showing a v-shaped deflection of <90° from the general trend of the contour line (i.e., lines tangent to the inflection point of the deflected portion of the contour line had to intersect at an angle of <90°), (2) a slope of greater than 0.5%, and (3) a downstream connection to a mapped stream not more than two stream orders higher than the added stream (i.e., 1st order added streams could connect to a 1st, 2nd or 3rd order stream, but not to a 4th or higher order stream and 2nd order added streams could not connect to 5th or higher order streams). This connection rule was developed to avoid adding streams where groundwater tables, controlled (lowered) by the higher order stream, would have been too deep to contribute to flows of an added tributary. However, a few additional streams may have been missed using this criterion. Figure 1 shows an example of streams added using the topographic rules outlined above. Figure 2 shows the resulting digital stream network for the Cow Swamp watershed.

Appendix 2. References for the Effect of Width on Nitrogen and Phosphorus Removal in Coastal Plain Riparian Buffers.

Vegetation Type	Flow Wype	N Species	Width (ft)	% N Removal	Study
grass	surface	total N	15	-15	Magette et al. 1989 [1]
grass and forest	subsurface	nitrate	26	33	King 2005 [2]
grass	surface	total N	30	35	Magette et al. 1989 [1]
grass	subsurface	nitrate	33	99	Schoonover & Williard 2003 [3]
forest	subsurface	nitrate	33	82	Schoonover & Williard 2003 [3]
forest	subsurface	nitrate	49	96	Hubbard & Sheridan 1989 [4]
grass and forest	subsurface	nitrate	49	67	King 2005 [2]
forestwetland	subsurface	nitrate	102	59	Hanson 1994 [5]
forestwetland	subsurface	nitrate	125	78	Vellidis et al. 2003 [6]
forest	subsurface	nitrate	164	94	Lowrance 1992 [7]
forest	subsurface	nitrate	164	99	Jacobs & Gilliam 1985 [8]
forest	subsurface	nitrate	180	83	Lowrance et al. 1984 [9]
forest	subsurface	nitrate	197	95	Jordan et al. 1993 [10]
grassforest	subsurface	nitrate	230	91	Hubbard & Lowrance 1997 [11]
forest	surface	nitrate	230	79	Peterjohn & Correll 1984 [12]
forest	subsurface	nitrate	279	94	Peterjohn & Correll 1984 [12]
forest	subsurface	nitrate	328	100	Spruill 2004 [13]

Buffer Width (ft.)	% P Removal	Study Reference	Notes
15	41	Magette et al. 1987 [14]	
30	53	Magette et al. 1987 [14]	
62	80	Peterjohn & Correll, 1984 [12]	
180	36	Lowrance et al. 1984 [9] Desbonnet et al. 1994 [15] Mayer et al. 2007 [16]	Values compiled from multiple sources. Used median removal value.
246	56	Lowrance & Sheridan 2005 [17]	
656	74	Casey & Klaine 2001 [18]	

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Appendix 3.
Planning Buffers for Tidal Wetlands
Christopher Bason, Scientific & Technical Coordinator, Center for the Inland Bays
(Updated October 05, 2007)

This paper uses existing local data to describe rates of tidal wetland migration into upland areas potentially regulated as wetland buffers. It is based on the concept that tidal wetlands move inland by processes of erosion at their bayward edges and by migrating over uplands at their landward edges.

1. Shoreline erosion in Rehoboth Bay during 1938-1981 ranged from 0.66 to 5.25 feet per year and was highly variable [1 and references therein].
2. The landward migration of tidal wetlands is surprisingly rapid and is controlled primarily by the slope of the adjacent upland, with wetlands migrating faster over gradually sloping uplands (Table 1.) [1].
3. Tidal wetlands also migrate in the upstream direction of stream or creek valley axes at even faster rates. But here, newly established tidal wetlands are generally confined to the narrow stream valley (Table 1.) [1].

Table 1. Rates of landward migration of tidal wetlands by adjacent upland slope from 1944-1989. Gradual Slope = <0.08 rise/run, Steep Slope = >0.09 rise/run *(pg. 131 [1])*.

Slope	**Indian River Bay**	**Rehoboth Bay**
Gradual	5.25 ft/yr	6.07 ft/yr
Steep	1.44 ft/yr	0.82 ft/yr
Valley Axis	16.40 ft/yr	4.56 ft/yr

3. The above historical rates of migration are likely conservative compared to today's rates of migration because:
   a. The Indian River Inlet has increased greatly in cross section and thus transmits a greater volume of water per tidal cycle thus increasing tidal amplitude, or the range of high and low tides[2]. The highest tides begin the conversion of adjacent uplands to tidal wetlands.
   b. Storm frequencies nearly doubled over the last century, creating more frequent and sometimes more powerful tidal surges inland [3].
   c. Certain tidal wetlands may be submerging under increased rates of sea-level rise, allowing surges to attenuate less on their path over marshes towards uplands [4, 5].

4. Using these conservative rates of migration, the minimum period of time (in years) upland buffers of different widths may be reasonably assumed to protect wetlands or shorelines are calculated (Table 2).
5. The rates of migration of tidal wetlands up stream or creek valleys are also presented to allow for anticipation of future extent of tidal wetlands (Table 3).

Table 2. Years upland buffers of different widths will provide any protection to tidal wetlands or waters

	Indian River Bay		Rehoboth Bay	
Upland Buffer Width	**Gradual Slope**	**Steep Slope**	**Gradual Slope**	**Steep Slope**
50’	10	35	8	61
75’	14	52	12	91
100’	19	69	17	122
200’	38	139	33	244
300’	57	208	49	366
400’	76	278	66	488
500’	95	347	82	610

Table 3. Length a tidal marsh moves upstream for different planning horizons. Mean marsh migration up tidal creeks (10.48 ft/yr) is the average of 4 locations in Indian River and Rehoboth Bays from 1944-1989.

Upstream Movement of Tidal Wetlands (ft)	Years
105	10
262	25
524	50
786	75
1048	100

5. Once these time periods have past, wetlands will have migrated through buffers into built or production lands and loss of these lands will begin. Two general scenarios will then occur: 1) the upland will be bulk-headed or diked or 2) the built or production land will be abandoned. The first scenario will prevent the tidal wetlands from migrating inland and will result in their loss at a rate equal to its bayshoreline erosion rate (see above) (Figure 1). The second scenario will allow the wetlands to maintain themselves but is unlikely as most private lands adjacent to the Bays are, or will soon be, developed with substantial economic investments

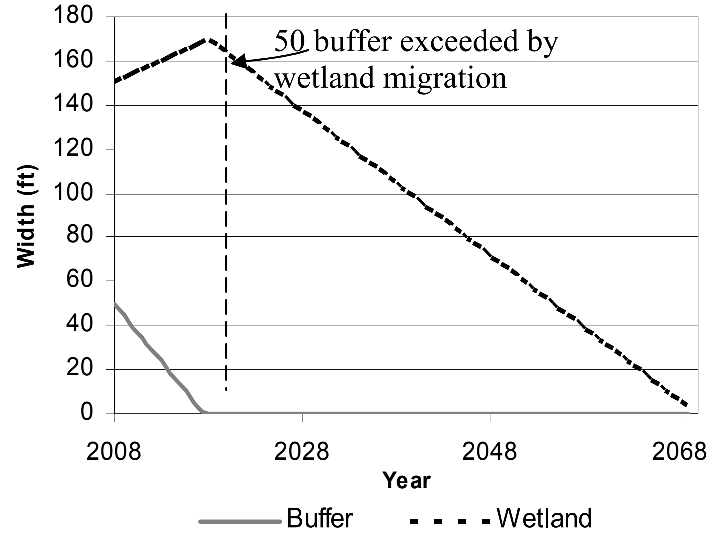

Figure 1. Conceptual change in width of upland buffers and tidal wetlands due to landward migration and erosion of tidal wetlands under for tidal wetlands with gradually sloping adjacent uplands and somewhat above average bayshoreline erosion.

6. Large-scale loss of tidal wetlands under this scenario will eliminate large acreages of existing biofilters and will release of huge amounts of stored nutrients into the Inland Bays. Loss of fish and bird nursery habitat, carbon storage and sequestration capacity, and other functions would likely change the entire nature of the Inland Bays.
7. Currently, many Inland Bays marshes appear unable to maintain their elevation with sea-level rise [1, 6-8] and may submerge in the near future, likely causing rates of inland migration to increase. Emerging stressors such as sudden wetland dieback may exacerbate this process.

Recommendation

To adequately protect the nutrient filtration and storage capacity of tidal wetlands under predictions of rising sea-level, upland buffers sufficient to allow inland wetland migration near a 100 year time horizon should be mandated. Special consideration should be afforded to the conservative estimates of wetland migration presented here, new estimations of the rates of future sea-level rise[9, 10], and the sensitivity of tidal wetlands to this process. Regulations should be developed based on the slope of adjacent uplands. Attention should be given to rates of migration up stream or creek valleys so that appropriate buffer widths may be allowed for in advance of migration.

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Appendix 4. GIS Analysis Workflow

1. Roughly determine onsite and offsite waterway and wetland features whose buffers would affect development
2. Determine what features would be provided buffers. Buffers of any wetlands and waterways that occur on adjacent undeveloped properties and that have more than half of their buffer width on the developing property should be required on the developing property.
3. Using topographic valley contours, the presence of riverine wetlands, historic and current aerial imagery, and best professional judgement, classify waterways as ditches or natural waterways. Natural waterways tend to occur within distinctly sloping topographic valleys and may have been excavated to improve drainage (channelized). Channelization may eliminate wetland conditions adjacent to streams. Topographic valleys are more conservative distinguishing features. Ditches are an extension of the natural drainage network. Ditches are often excavated through flats wetlands or uplands with high water tables. Ditches generally do not support topographic valley contours. However, topographic maps often depict contour lines on the top of ditch banks. Special attention must be given to the Poorly Drained Region of the watershed when distinguishing ditches from natural streams. This region was almost entirely wetlands prior to European colonization and has undergone landscape level drainage and profound water table lowering. Here natural drainage was likely dominated by forested sloughs that slowly delivered water through tortuous paths across the wetland landscape. Some of these sloughs remain and are characterized by very slight "valley" slopes that generally are not distinquishable from topographic maps. It's the opinion of the author that LIDAR derived digital elevation maps would provide great insight into these drainage features.
4. Using best professional judgement, classify ditches as minor or major. Minor ditches are generally terminal or connector ditches, have very small watersheds, and if the entire upstream ditch network was incapacitated no apparent issues of concern for development would occur.
5. Classify minor ditches as fillable (or otherwise able to be disconnected from the drainage network) or not. Minor ditches are fillable if no upstream drainage impacts to existing landuse would result from their incapacitation.
6. Union wetland features whose buffers will affect development. *This may be unnecessary but sometimes the continguity function of the buffer command on arcview does not work.*
7. Clip wetlands to developing property on PLUS layer.
8. Erase clipped wetlands layer from developing property to create developable area shapefile.
9. Buffer non-fillable ditches.
10. Buffer natural waterways.
11. Buffer freshwater wetlands.
12. Buffer tidal features.
13. Further determine if buffers of offsite features would be required on development.
14. Determine what if any areas will not be buildable due to buffer arrangement. If areas were very small and access to them was not conducive based on the layout of buffers on the site then they were considered isolated. This means that the buffer would not be altered to allow access to these pieces of the development and they would functionally be part of the buffer. If they were situated such that access through the buffer would be reasonable based on other site features such as existing roads and layout then they were not considered isolated. For example road access across natural waterways in their

natural condition was generally assumed to not occur. Road access across ditches or natural waterways where the stream was channelized and wetlands were filled was assumed to occur in all cases.

15. Create a shapefile for areas not buildable due to buffer arrangement.
16. Batch Clip all shapefiles to the development area.
17. Merge all the clipped shapefiles.
18. Calculate the acreage of the total buffer and by feature type using the merged shapefile's table.
19. Determine the amount of nonforested buffer to restore by clipping buffer to areas that are both not forested and not likely to remain in their current developed state.
20. If tidal wetlands with gradually sloping adjacent uplands are present, buffer tidal areas with 150' buffers for the optimum recommendation and 80' for the sufficient recommendation. These are the portions of the tidal buffer to be restored to forest, call them tidalrestoreclip.
21. Merge the clipped nontidal waterways, wetlands and the tidal buffer restoration shapefiles.
22. Union the features of this merged shapefile.
23. Determine the amount of nonforested buffer to restore by clipping this buffer to areas that are both not forested and not likely to remain in their current developed state.
24. Calculate area of buffer to be restored.

Table 1. GIS layers used in this study. All layers should be available from the Delaware Datamil, the State of Delaware, Sussex County, or the Center for the Inland Bays.

Layer Name	Filename	Description
State Wetlands Mapping Project (SWMP) Layer	Swmp.shp	Wetlands mapped using 1992 aerial photography and other information. DNREC.
Sussex County Water Lines 1999	Suswtr99.shp	Hydrography. DNREC.
Preliminary Landuse Service Project Areas (February 2004 to January 2007)	Project_areas.shp	Developments proposed to the State. State of Delaware.
2002 Delaware Landuse	2002_delaware_lulc.shp	State of Delaware digitized landuse. Delaware Datamil.
Sussex County Tax Parcels	Parcels.shp	Updated May 2007. Sussex County online.
State of Delaware Agricultural Easements	State_ag_easements.shp	Agricultural lands preserved in perpetuity. State of Delaware.
Inland Bays Simplified Hydrogeomorphic Regions	Inlndbyshgmrgsmpl.shp	CIB created watershed regions simplified from USGS studies. CIB.
Inland Bays Watershed	Outline.shp	Watershed outline per the DNREC whole basin initiative. DNREC.
USGS topographic quadrangle maps	Susseast.tiff	Mosaic of quandrangles for the eastern half of the county. DNREC.
Hypsography	Example: hypso48.shp	Line file of topographic contours extracted from USGS

		quadrangles. Available from Delaware Geological Survey online.
2002 Aerial photography	Sussex.sid	Delaware Datamil.
Historical Aerial photography		Delaware Datamil.